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Effect of Sowing Date on Some Agronomical Characteristics of Rye Cultivars in Iraq

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Abstract: The introduction of rye cultivation in Iraq necessitates the implementation of agrotechnological experiments. Two-year irrigated field experiments were carried out in Al-Muthanna Governorate (in the southwestern region of Iraq) in 2021/2022 and 2022/2023 to evaluate the performance of three European rye cultivars introduced to Iraq, focusing on the most significant agronomical and morphological characteristics. Three sowing dates (01 November, 15 November and 01 December) were tested in a split plot, randomized complete block design. We observed that both the cultivar and sowing date, but not the crop year, influenced the studied characteristics. In general, the early sowing dates enhanced the growth and development of rye and resulted in a higher yield compared to the later sowing dates. We observed that all evaluated rye cultivars can be grown safely in the agroclimatic and soil characteristics of this region. The grain yield was 3.1, 4.2 and 6.9 t ha^{-1} on average for all the sowing dates, and the above ground biomass results were 13.6, 12.0 and 22.9 on average for all sowing dates in 'Krzyca', 'Dańkowskie złote' and 'Horyzo', respectively. In addition, the highest grain yield (8.8 t ha^{-1}) was harvested in 'Horyzo' when it was sown on 01 November; thus, we recommend choosing 'Horyzo' for cultivation in Iraq and sowing it in early November. Although further study is required to improve agro-technology (such as the nutrient supply) by using a larger number of cultivars, we can conclude that rye can be grown safely in Iraq under irrigated conditions.

Keywords: *Secale cereale* L.; yield structural elements; adaptability

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1. Introduction

In the 21st century, the risk of global food security has increased, mainly due to the effects of climate change [1–4]. Farmers should incorporate adaptation strategies into crop production systems, in addition to using resistant cultivars, proper irrigation and soil management techniques, and should even introduce new species for cultivation under specific agro-climatic conditions, such as rye cultivation in Iraq [5–9].

In addition to the dominant oil sector, agriculture is one the main sectors of the Iraqi economy and includes the cultivation of cereals (wheat, barley), fruits (dates, orange), vegetables (tomato, cucumber) and livestock. As limited land and water resources, low productivity and variable yields are major challenges in Iraq, efforts are needed to improve agricultural practices and productivity [10]. Moreover, using environmentally friendly techniques and strategies should assist in improving soil fertility, preserving water and increasing agricultural productivity in a sustainable manner [11]. Climate change (severe floods, risk of desertification) may further worsen the situation regarding Iraqi agriculture [12]; therefore, improving water management and increasing the efficiency of agricultural practices have become primary considerations [13]. The food supply in Iraq has been based on two main crops (wheat and rice) and is highly dependent on food imports; thus, the introduction of new species into cultivation has become necessary [14,15]. Additionally, it has become important to choose plant species and cultivars for cultivation that use much less water [16].

Several specific barriers have been identified that cereal farmers face in adapting to climate change effects. The evaluation of questionnaires, obtained from a selected 227 farmers around Iraq, highlighted the lack of knowledge of farmers about the effect of climate change on different crops and agricultural techniques and practices. A solution can be to enhance the knowledge and awareness by training programs and extension services. Moreover, the changes and unexpected extreme climatic conditions can decrease biological diversity, and it is necessary to maintain its continuity and its availability [17]. Technology development experiments have already started with testing different European triticale varieties in Iraq to introduce the plant to cereal farmers [18,19].

Rye (*Secale cereale* L.) is an important cereal grass that belongs to the *Poaceae* (*Gramineae*) family. Cultivated rye is derived from *S. montanum* [20], and its genetic diversity center is in Central and Southwest Asia [21]. However, its cultivation probably began in Northern Europe, where it is still the most popular cultivated cereal [21]. The main global producers are the Russian Federation, Poland, Germany and Belarus [22].

According to its production area, rye is a crop of minor importance that is suitable for human consumption, animal feed and industrial processing, for example, biogas production [23,24]. For human consumption, rye is usually ground into flour or whole-meal flour for baking various types of bread, mostly "black bread", but the whole grain can also be boiled, and beverages (beer, whisky and vodka) can even be made from it [25]. However, about 50% of the rye yield is used for animal feeding, most frequently as grain, but young plants may be grazed [25]. Rye straw also may be used in animal husbandry as litter or feed, and it may be utilized in some industrial areas [25]. Moreover, rye can be sown in mixed culture with hairy vetch (*Vicia villosa* Roth.) as a support plant [26].

Rye is a prominent small-seeded, minor cereal crop that has exceptional tolerance to different abiotic stresses such as drought, salt and aluminum, and it has excellent cold tolerance [23,27]. Its nutrient use efficiency is good, and it can produce a good yield on low humus content soil compared to winter wheat [28,29]. Due to the good adaptation ability of rye, it can be easily adapted to changing climatic conditions [30,31].

Rye is not grown as a main crop in Iraq; it is mostly a plant of cooler climate areas, as in Europe. The climate is hot in summers and relatively mild in winters in Iraq, which are more favorable conditions for crops such as wheat and barley [10].

Introducing rye, as a new plant species in Iraq has potential benefits, but there are aspects that should be considered. The introduced crop can increase the agrobiodiversity; it can be a new source of fiber, minerals and vitamins, and its cultivation can provide a great opportunity to utilize the weak soils of the country. The cultivation of rye in Iraq can be risky, due to the climate of the country, which affects the yield and seed quality. Since Iraq can be divided into four different climatic zones—from warm desert climate to continental [32]—and the adaptability of rye is excellent, these risks can be reduced.

In order to adapt rye to different growing environments and meet the needs of food security and economic development, a comprehensive examination of the new plant species is necessary. There are some published attempts to introduce new cereals into Iraq, including field experiments with rye [33] and triticale [34]. The performance of different rye cultivars, the determination of optimum seed rates and their interaction were studied recently [33].

The sowing date of rye affects both the plant morphological parameters and yield [35]. The optimal sowing date depends on the given region's climate conditions. Winter rye is able to germinate, grow and develop tillers at lower temperatures, which allows for a later sowing date. The date of sowing significantly influenced the plant growth, and the development of higher plants was enhanced by an early sowing date [36]. Without irrigation, the crop year also was proven to be an important factor: more precipitation resulted in higher plants [36]. Furthermore, the sowing date affected the heading date, the occurrence of fusarium head blight and lodging in experiments in Kentucky (USA) [35]. The number of tillers per m^2 was significantly affected by the sowing date, where the results were the highest (604.5) with the earliest sowing and the lowest (515.0) with the latest sowing date [35].

The spike parameters of rye are important components of the yield. The yield structural elements such as the number of spikelets per spike, number of grains per spike and weight of grains per spike are influenced by the cropping system and the weather conditions [37]. The winter rye yield has a tight positive correlation with the spike weight, grain weight per spike and grain number per spike [38]. The morphological parameters and yield components of rye spikes are determined both by genetic properties and environmental factors [39]. The plant height depends on both the environment and cultivars [40]. The grain number per spike, grain weight per spike, 1000 grain weight (TGW) and grain weight per plant correlated positively with the plant height of winter rye [41].

Despite the fact that rye can be grown almost all over the world, it is not traditionally cultivated in Iraq; thus, some agrotechnological elements should be fitted to the local conditions. The primary aim of our study was to evaluate the performance of three European rye cultivars newly introduced to the country. The specific aims and objects of this study were (i) to study the most important agronomic characters (plant height, flag leaf area, spike length, number of spikes per m^2, number of grains per spike, thousand-grain weight, grain yield, above ground biomass and harvest index) of the selected rye cultivars in the southwestern region of Iraq; (ii) to study the effects of cultivars and sowing date on the morphological and yield traits and to uncover the relationships between them; (iii) to seek the most suitable cultivar for cultivation in Iraq; and (iv) to determine the best sowing date for the tested cultivars.

2. Materials and Methods

2.1. Description of Experimental Site and Characterization of Climate and Soil

The field experiment was conducted in 2021/2022 and 2022/2023 near the city of Al-Rumaitha, which is in Al-Muthanna Governorate (Samawah, Iraq) (31.5209300° N 45.2016870° E) (Figure 1). The province is in the southwestern part of Iraq, bordering Saudi Arabia and Kuwait. The main meteorological data of the experimental site are presented in Table 1.

Table 1. Meteorological data of experimental site in both growing seasons (2021/2022 and 2022/2023).

		Winter Rye Growing Season of 2021/2022					
		November	December	January	February	March	April
Temperature °C	Max.	20.30	15.90	17.90	19.52	26.66	32.60
	Min.	9.00	4.70	3.70	2.10	13.20	18.90
	Average	14.65	10.3	10.8	10.81	19.93	25.75
Accumulative temperature		307.5	182.9	198.4	185.89	481.43	460.5
Precipitation (mm)		0.7	2.349	4.2	0.07	1.41	3.2

Table 1. *Cont.*

		Winter Rye Growing Season of 2022/2023					
		November	December	January	February	March	April
Temperature °C	Max.	25.10	17.70	17.10	17.46	24.65	30.30
	Min.	7.1	3.7	2.7	1.82	10.99	16.5
	Average	16.1	10.7	9.9	9.64	17.82	23.4
Accumulative temperature		351	195.3	170.5	151.96	416.02	570
Precipitation (mm)		0.5	1.019	5.3	0.13	0.91	4.9

Figure 1. Location map of experimental site.

The soil type of the experimental plots was silty clay loam, and soil samples were collected at a depth of 0–30 cm from nine sample sites chosen randomly. The soil samples were analyzed in the laboratory of the College of Agriculture, University of Al-Muthanna, before sowing. After removing the plant remains, the soil was air-dried and ground well, and then it was sifted through a sieve with holes of 2 mm in diameter. Thereafter, the dried soil samples were mixed and homogenized, representative samples were taken, and then the physical and chemical tests were performed [42–44]. The main soil characteristics are summarized in the Table 2 (as the averages of both growing winter seasons).

Table 2. The main characteristics of soil samples collected from the experimental field at a depth of 0–30.

Soil Characteristic	Value
pH	7.22
Electrical conductivity (dS m^{-1})	2.7
Organic matter (%)	0.56
Available nitrogen (mg L^{-1})	25.16
Available phosphorous (mg L^{-1})	9.5
Available potassium (mg L^{-1})	181.0

2.2. Plant Material

The seeds of three certificated European rye cultivars (‘Krzyca’, ‘Dańkowskie złote’ and ‘Horyzo’) were imported from Poland. ‘Krzyca’ is an old cultivar in Poland, which has great baking quality, and its grain has high protein, flavonoid and carotenoid contents. In addition, this cultivar is suitable for organic production [45]. ‘Dańkowskie złote’ has been the most widely cultivated rye cultivar in Poland for many years, and it can be grown on all soil types. It can produce a high and very stable yield over the years, due to its drought tolerance and early growth vigor. The plants are of medium height, have good resistance to lodging and are resistant to several diseases. It is a large-grained crop with good grinding and baking value. ‘Daukowskie złote’ has wide adaptability, and its grains contain high protein (11.6%) and digestible starch (58.77%) contents [46]. ‘Horyzo’ is a type of common rye registered in Poland since 2011. This cultivar is characterized by high yield potential and tolerance to different soil and climate conditions. ‘Horyzo’ can also be grown safely on acidic soils. It is characterized by excellent disease resistance and a very good ability to suppress weeds. Its grain shape is uniform and has a high thousand-grain weight (TGW). The grain has a significant protein content, so ‘Horyzo’ provides valuable and nutritious grains.

2.3. Experimental Design and Treatments

The experiments were set in a split plot, randomized complete block design with three replications, and protection rows were employed. The three sowing times (1 November, 15 November and 1 December) occupied the main plots, while the sub-plots were devoted to the three European rye cultivars. The factors were distributed randomly within each experimental unit, so the total number of experimental units was 27 (Figure 2). The length and the width of the experimental plot were 2.0 m, and there were 10 rows within the plots. The distance between the rows was 20.0 cm, and a 120 kg ha^{-1} seeding rate was applied, as it is common agrotechnical practice for wheat and barley belonging to the same family *Poaceae* with the same row distance.

Figure 2. Experimental plots of rye adaptation field experiments near the city of Al-Rumaitha (Al-Muthanna Governorate), in crop year 2021/2022 (**A**) and 2022/2023 (**B**).

2.4. Agricultural Practices

Land preparation and soil service operations were carried out before sowing, including removing the remains of the previous crop (faba bean), plowing using a rotary plow and then smoothing using disc harrows and a soil leveler machine. After sowing, the first irrigation was performed for each sowing date. To enhance emergence, irrigation was used for the crop whenever it was necessary. The soil was fertilized with phosphate (80 kg ha^{-1}) in the form of triple superphosphate (21% P_2O_5) applied before sowing, during soil preparation. Nitrogen at the recommended dose of 120 kg ha^{-1} was added in the form of urea fertilizer (46% N) in two equal portions: the first at the emergence stage (two weeks after sowing) and the second at the tillering stage. Potassium fertilizer (80 kg ha^{-1}) in the form of potassium sulfate (42% K_2O) was applied before sowing, based on the wheat crop recommendation. All cultivars were harvested according to the date of their full maturity (Table 3), and the recommendations of the improved package of agricultural practices for growing rye were followed, except for the factors under study. In the experiment, plants were not treated to protect against pests and diseases, and weeds were managed by hand.

Table 3. Summary table of treatments, including cultivars, crop years and sowing dates. Harvesting dates for different treatments are also presented.

2021/2022			2022/2023		
Cultivar	**Sowing Date**	**Date of Harvest**	**Cultivar**	**Sowing Date**	**Date of Harvest**
Krzyca	01.11.2021	09.04.2022	Krzyca	01.11.2022	08.04.2023
Dańkowskie złote	15.11.2021	12.04.2022	Dańkowskie złote	15.11.2022	10.04.2023
Horyzo	01.12.2021	16.04.2022	Horyzo	01.12.2022	13.04.2023

2.5. Agronomic Characteristics Studied

Different morphological and yield parameters, including yield structural elements were observed. Plant height (cm) was measured using a metric measuring device from the soil surface level to the end of the terminal spikelet, on ten main stems taken randomly from each experimental plot before harvest, and then the average was calculated. The flag leaf length and width were measured on the main stem using a ruler at the flowering stage, in which the leaf area reached its maximum. Ten plants from each experimental plot were taken randomly, and according to the equation below, the flag leaf area (1) was estimated [47]:

$$\text{Flag leaf area (cm}^2) = \text{Flag leaf length (cm)} \times \text{Flag leaf width (cm)} \times 0.95 \quad (1)$$

The length of the spike (cm) was measured on the main stem, from the base of the basal spikelet where the first spikelet connects to the spikelet axis to the tip of the upper terminal spikelet without the top. Ten spikes were measured at random from each experimental plot. The number of spikes was counted for all plants harvested from the two middle rows of each experimental plot after reaching full maturity stage and then converted to a square meter basis (number of spikes m^{-2}). The number of grains per spike was calculated from the average number of grains for ten spikes taken at random, after manually splitting these spikes individually and counting the number of grains for each spike. One thousand grains were collected and counted for each experimental plot, and each sample was weighed using a balance to determine the thousand-grain weight (TGW; g). The total grain yield was calculated after the grain yield of the plants from the two middle rows was harvested from each experimental plot and processed as follows: the grains were air dried, threshed, and the moisture content of the grains was adjusted to 13.5% and then weighed in kg and converted to ton ha^{-1}. The above ground biomass (AGB) was estimated as follows: the total above ground biomass (straw together with grain yield) from the two middle rows in each experimental plot was harvested and weighed, and then it was converted to ton ha^{-1}. Finally, the harvest index (HI %) (2) was calculated using the following formula [48]:

$$\text{HI \%} = (\text{Grain yield kg per ha})/(\text{AGB kg per ha}) \times 100 \quad (2)$$

2.6. Statistical Analysis

Data for the plant height, flag leaf area, spike length and number of grains per spike were collected from ten plants in each experimental plot. Data on the number of spikes, total grain yield and above ground biomass were collected from the two middle rows in each experimental plot. All data were collected once in specific development stages. To reveal which factor (crop year, cultivar or sowing date) plays a more important role in the formation of the main agronomic characteristics (recorded variables), multivariate tests including all factors were performed. Since crop year showed no significant effect, the data from both crop years were further analyzed together. The mean effects of cultivar and sowing date were further evaluated with Two-Way Analysis of Variance (ANOVA) followed by an LSD Post Hoc Test ($p < 0.05$). Finally, to clarify the effect of cultivar and sowing date, One-Way ANOVA followed by the LSD Post Hoc Test ($p < 0.05$) was performed after splitting the data. The cultivar × sowing date treatment combinations were ranked based on the averages of the examined agronomic characteristics, and then the ranking averages were calculated. Pearson correlation analyses were performed to detect relationships among all recorded variables. All analyses were performed using SPSS software, version 22.0 (SPSS®) for Windows.

3. Results

The field experiments were performed with winter rye during two seasons, three cultivars were involved, and three sowing dates were tested. According to the multivariate test, we found that the crop year had no significant effect on the studied variables, whereas the cultivar was the most significant factor affecting them ($p < 0.001$) (Table 4). The cultivar × sowing date interaction was also highly significant ($p < 0.001$).

Table 4. Summarized results of multifactorial and multivariate test (Wilks' lambda).

Effect	Value	F	Hypothesis df	Error df	Significance
Intercept	0.001	2909.133	9	28	<0.001
Crop year	0.890	0.384	9	28	0.933
Cultivar	0.041	12.228	18	56	<0.001
Sowing date	0.389	1.879	18	56	0.038
Crop year × Cultivar	0.879	0.207	18	56	1.000
Crop year × Sowing date	0.929	0.116	18	56	1.000
Cultivar × Sowing date	0.075	2.942	36	106.67	<0.001
Crop year × Cultivar × Sowing date	0.123	0.424	9	31	1.000

Since there was no significant effect of crop year, we further analyzed the variance in the data of both years together, to reveal the effect of cultivar and sowing date.

3.1. Main Effects of Cultivar and Sowing Date

Summarized results of the Two-Way ANOVA test are presented in Table 5, whereas the results of the Two-Way ANOVA test for each studied trait are presented in Table S1.

Table 5. Summarized results of Two-Way ANOVA test (Wilks' lambda).

Effect	Value	F	Hypothesis df	Error df	Significance
Intercept	0.001	3505.140	9	37	<0.001
Cultivar	0.045	15.374	18	74	<0.001
Sowing date	0.402	2.369	18	74	0.005
Cultivar × Sowing date	0.08	3.747	36	140.39	<0.001

All observed characteristics were significantly affected by cultivar in the average of all sowing dates, except for the number of spikes per m^2. In general, the 'Horyzo' cultivar showed higher values than the others, although the TGW and HI results of 'Dańkowskie złote' did not differ significantly (Figure 3).

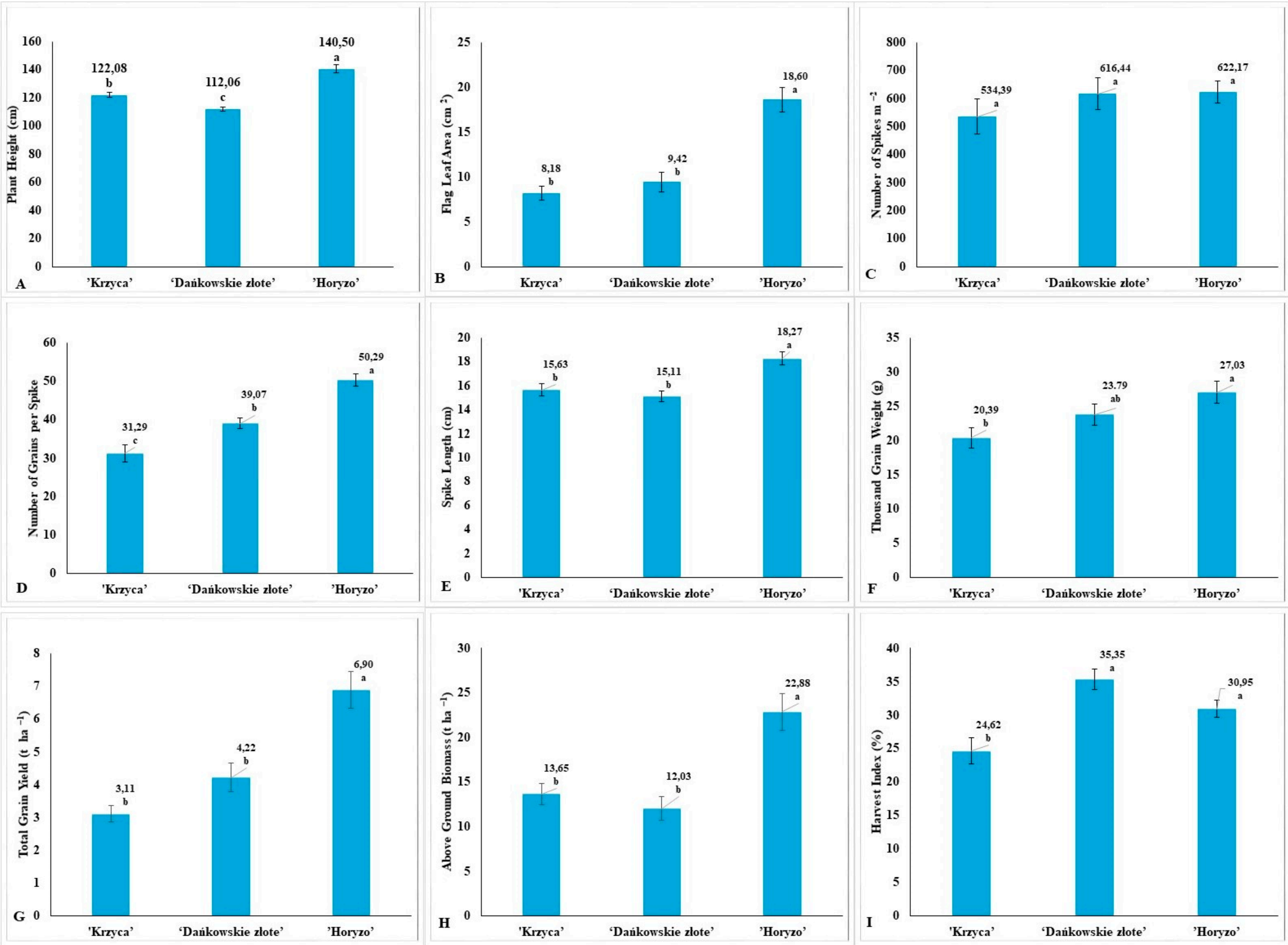


Figure 3. Effect of rye cultivar on the plant height (**A**); the flag leaf area (**B**); the number of spikes m^{-2} (**C**); the number of grains per spike (**D**); the spike length (**E**); the thousand-grain weight (**F**); the total grain yield (**G**); the above ground biomass (**H**), and the harvest index (**I**). Each column shows the means of each cultivar with standard error (±SE) (the average of each sowing date). Different lowercase letters indicate significant differences ($p < 0.05$) in the means between cultivars according to the LSD.

In addition, the most characteristics also showed variance caused by sowing date, except for the thousand-grain weight and harvest index (Figure 4).

3.2. *Effects of Cultivar and Sowing Date on Morphological and Yield Characteristics*

The variance analyses showed higher F values for cultivar effects in the morphological and yield characteristics, compared to sowing date effects, except for the number of spikes m^{-2}. A significant cultivar × sowing date interaction also could be detected in the case of plant height and thousand-grain weight (Table 6).

The detailed ANOVA tables with LSD Post Hoc test results are presented in Tables S2–S5.

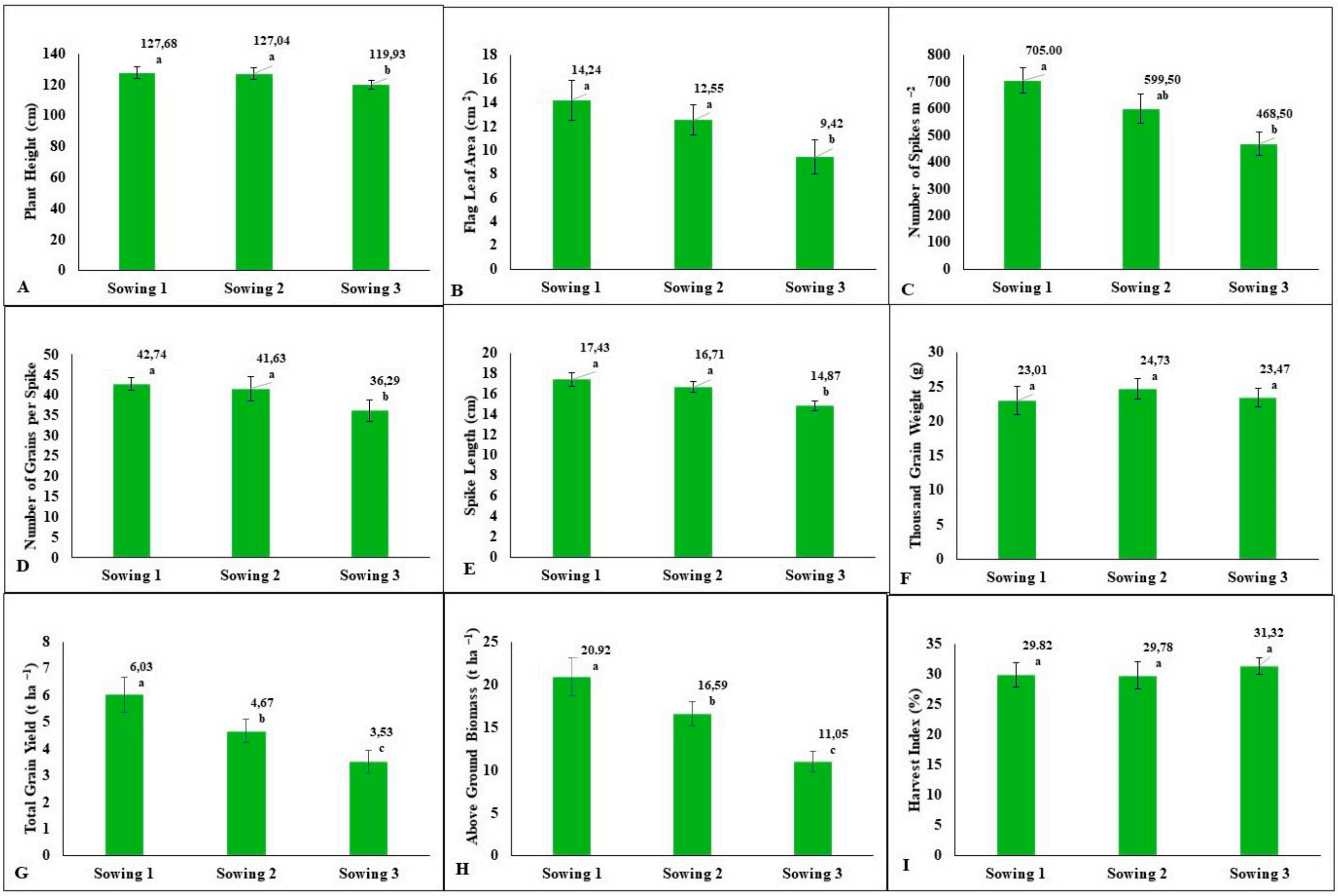


Figure 4. Effect of sowing date on the plant height (**A**); the flag leaf area (**B**); the number of spikes per m^{-2} (**C**); the number of grains per spike (**D**); the spike length (**E**); the thousand-grain weight (**F**); the total grain yield (**G**); the above ground biomass (**H**), and the harvest Index (**I**). Each column shows the means ± SE of sowing date (the average of each cultivar). Different lowercase letters indicate significant differences ($p < 0.05$) in the means between sowing dates according to the LSD.

Table 6. Variance analyses results for studied characteristics: F values. Abbreviations: CV: cultivar; SD: sowing date; PH: plant height cm; FLA: flag leaf area cm^2; SN: spike number m^{-2}; GN: grain number $spike^{-1}$; SL: spike length; TGW: thousand-grain weight; GY: grain yield; AGB: above ground biomass; HI: harvest index.

Source of Variation	PH	FLA	SN	GN	SL	TGW	GY	AGB	HI
CV	63.53 **	33.21 **	1.12 ns	35.50 **	14.227 **	6.55 **	29.60 **	23.15 **	12.21 **
SD	5.65 **	6.11 **	6.50 **	4.62 *	8.611 **	0.47 ns	12.14 *	16.58 **	0.32 ns
CV × SD	3.12 *	0.71 ns	2.31 ns	2.18 ns	0.009 ns	6.29 **	0.97 ns	1.52 ns	2.39 ns

* $p < 0.05$; ** $p < 0.01$; ns: non-significant.

3.2.1. Effect of Cultivar and Sowing Date on Plant Height of Rye

We found that the plant height was influenced by both cultivar and sowing date and by the interaction between them. However, we found that the sowing date only affected the height of the plant in the case of 'Horyzo' and 'Dańkowskie złote': the latest sowing date resulted in significantly lower plants compared to both earlier sowing dates (Figure 5). Regarding the cultivar, the plant height of 'Horyzo' was significantly higher than that of the other cultivars (except for the latest sowing date for 'Krzyca').

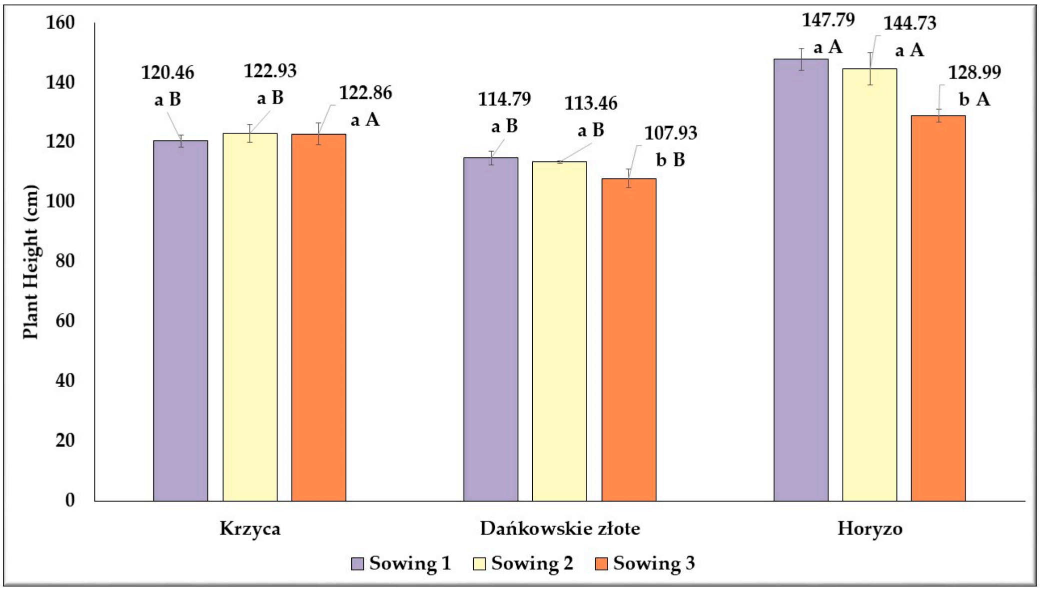


Figure 5. Effect of cultivar and sowing date on the plant height (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.2. Effect of Cultivar and Sowing Date on the Flag Leaf Area

Both factors significantly affected the size of the flag leaf area. The results of 'Horyzo' were significantly higher than those of the other cultivars for all sowing dates (Figure 6). The flag leaf areas of the 'Krzyca' and 'Dańkowskie złote' cultivars were almost the same, except for the second sowing date, when it was significantly larger in 'Dańkowskie złote' than in 'Krzyca'. Although late sowing dates seemed to result in smaller leaf areas, differences were only significant between the first and last sowing date for 'Krzyca' and 'Dańkowskie złote'.

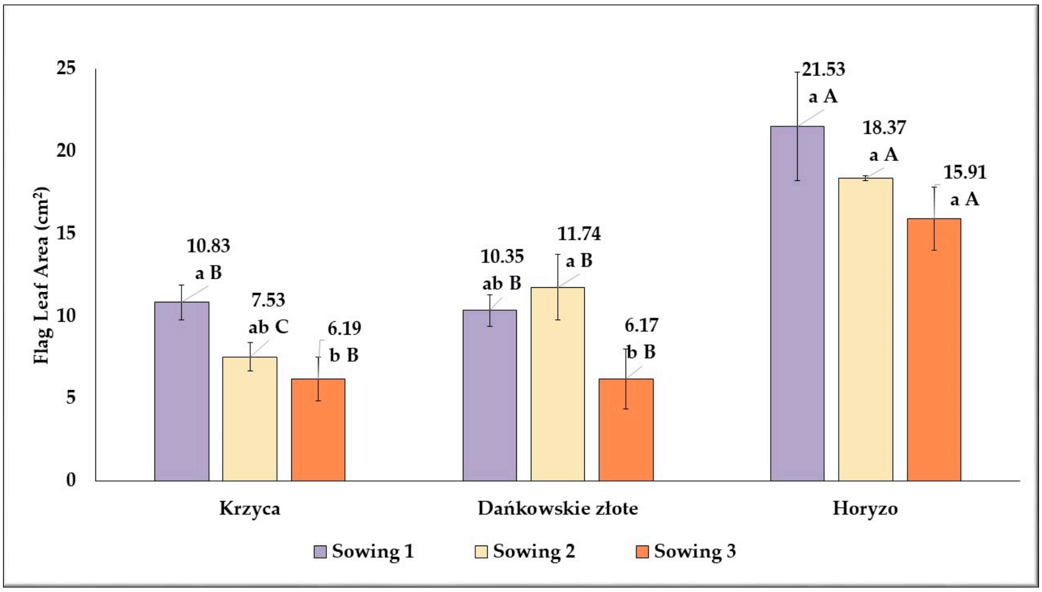


Figure 6. Effect of cultivar and sowing date on the size of the flag leaf area (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.3. Effect of Cultivar and Sowing Date on the Number of Spikes

The sowing date proved to be an important factor affecting the number of spikes per m^2. The most spikes (800 spikes m^{-2}) were found in the 'Dańkowskie złote' cultivar in the earliest sown plots, although there was no significant difference between the cultivars' results for the first and second sowing dates (Figure 7). However, 'Horyzo' produced significantly more spikes (593.83 m^{-2}) than 'Krzyca' (336.17 m^{-2}) in the case of the latest sowing date. The latest sowing date significantly reduced the number of spikes m^{-2} in the case of 'Krzyca' and 'Dańkowskie złote '. The first sowing date resulted in a significantly higher number of spikes m^{-2} in the case of 'Horyzo'.

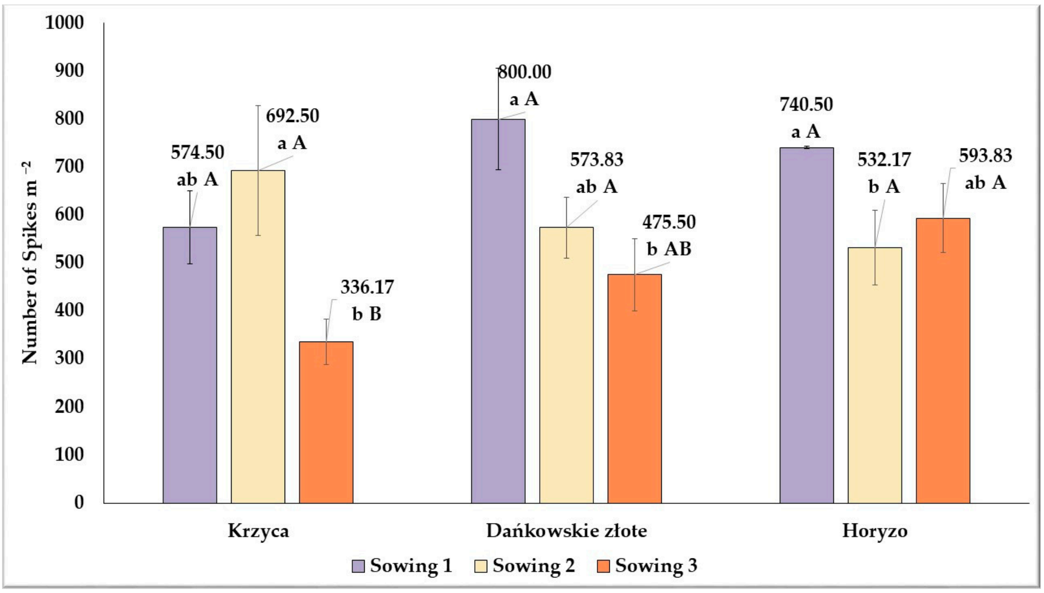


Figure 7. Effect of cultivar and sowing date on the number of spikes m^{-2} (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.4. Effect of Cultivar and Sowing Date on the Number of Grains Per Spike

The number of grains per spike was significantly influenced by the cultivar, whereas the effect of sowing date was much less significant. The number of grains per spike ranged between 24.52 and 52.18 (Figure 8). The highest number of grains per spike (52.18) was recorded in the 'Horyzo' cultivar, and it was significantly higher than those of the 'Krzyca' and 'Dańkowskie złote' cultivars (except for results obtained from the plots of 'Dańkowskie złote' sown at the second date). The least grains per spike (24.52) was counted in the 'Krzyca' cultivar, and it was significantly different from the other cultivars in the same (the latest) sowing date. The latest sowing date resulted in a significantly lower number of grains per spike in the case of 'Krzyca'.

3.2.5. Effect of Cultivar and Sowing Date on the Length of Spikes

Both factors played an important role in the variability of the length of spikes. The spike length ranged between 13.72 and 19.35 cm (Figure 9). The longest spikes were produced by the 'Horyzo' cultivar (19.35 cm; 18.68 cm; 16.77 cm), which was significantly different from results of 'Krzyca' and 'Dańkowskie złote' except for the 'Krzyca' cultivar sown on the first sowing date. The latest sowing date resulted in significantly shorter spikes in each cultivar.

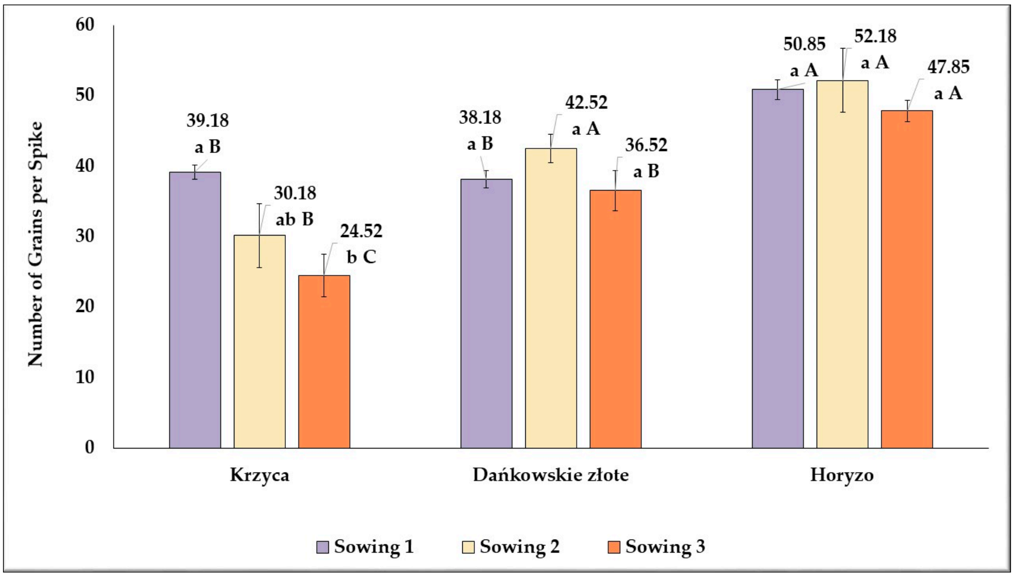


Figure 8. Effect of cultivar and sowing date on the number of grains per spike (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

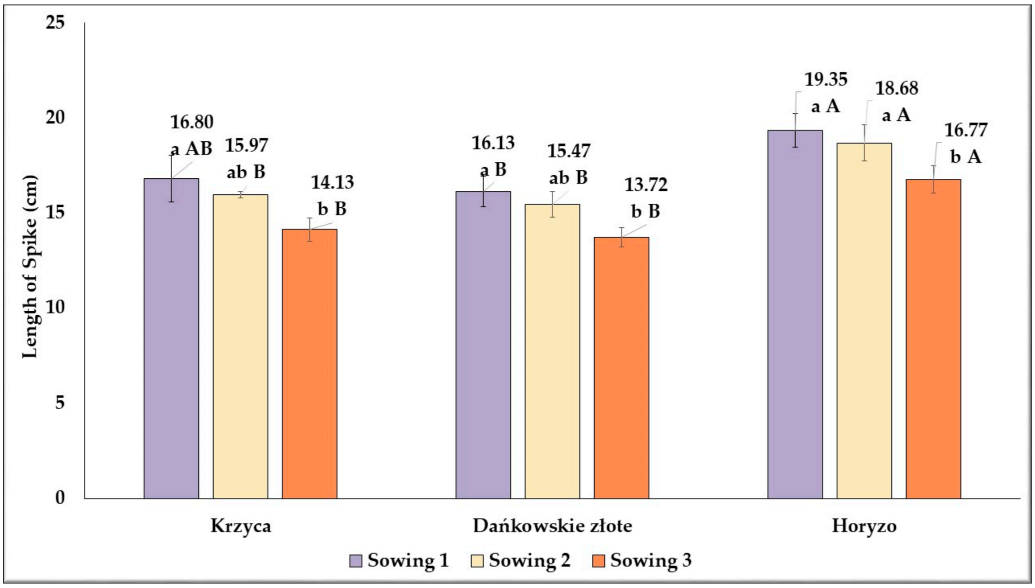


Figure 9. Effect of cultivar and sowing date on the length of spikes (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.6. Effect of Cultivar and Sowing Date on the Thousand-Grain Weight

Cultivar was the main factor affecting the variance in the thousand-grain weight. The TGW ranged between 31.70 and 17.33 g (Figure 10). The highest one was obtained for the 'Horyzo' cultivar sown on the first date (31.70 g), but it was not significantly different from that of 'Horyzo' sown on the second sowing date (28.70 g) and from that of the 'Dańkowskie złote' cultivar sown on the second and third sowing dates (27.87 and 26.17 g, respectively). Sowing date did not affect the TGW of 'Krzyca' at all, whereas the first sowing date resulted in a lower TGW in the case of 'Dańkowskie złote'. Moreover, the last sowing date significantly reduced the TGW of 'Horyzo'.

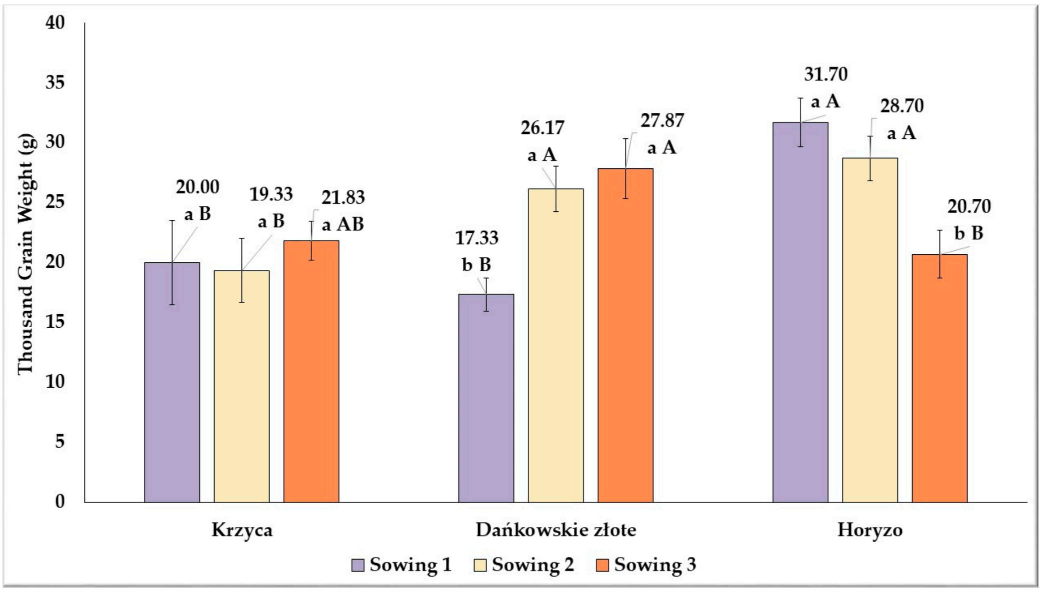


Figure 10. Effect of cultivar and sowing date on the thousand-grain weight (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.7. Effect of Cultivar and Sowing Date on the Grain Yield

Both the cultivar and sowing date significantly affected the grain yield per hectare (Figure 11). The grain yield varied between 8.82 t ha^{-1} and 2.34 t ha^{-1}. The highest value was measured in 'Horyzo' on each sowing date (8.82 t ha^{-1}; 6.81 t ha^{-1}; 5.08 t ha^{-1}), which significantly differed from the results of 'Krzyca' and 'Dańkowskie złote'. The lowest yield was measured for 'Krzyca' (3.75 t ha^{-1}; 3.24 t ha^{-1} and 2.34 t ha^{-1}) for all sowing dates. The latest sowing date reduced the total grain yield significantly in each cultivar.

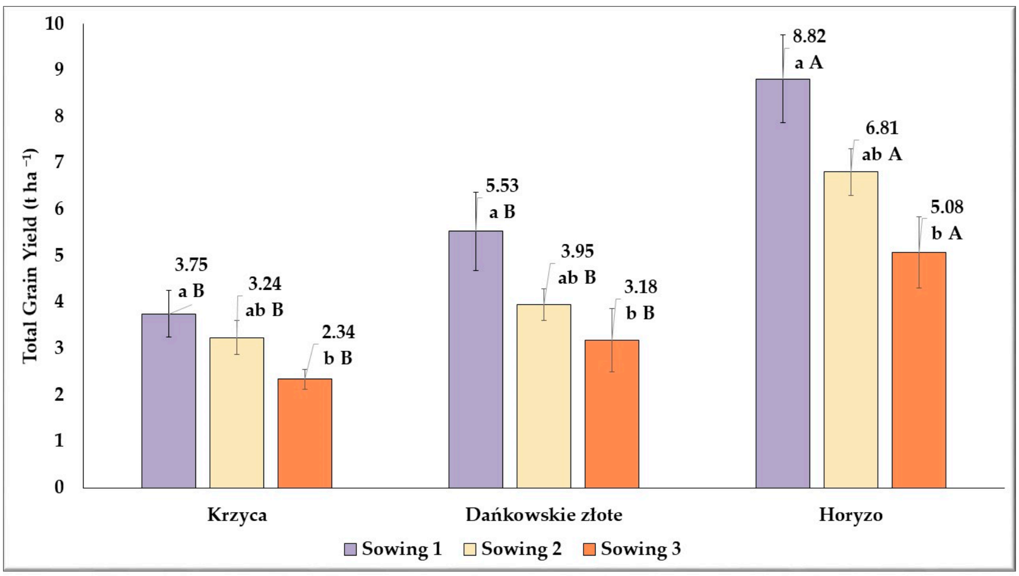


Figure 11. Effect of cultivar and sowing date on the total grain yield (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.8. Effect of Cultivar and Sowing Date on the above Ground Biomass

Both the cultivar and sowing date significantly influenced the AGB per hectare (Figure 12), which varied between 7.77 t ha^{-1} and 30.10 t ha^{-1}. All sowing dates resulted in the significantly highest yield in 'Horyzo' compared to those of other cultivars. Significant differences were not observed in the AGB of 'Krzyca' and 'Dańkowskie złote', except for the second sowing date, when the result of 'Dańkowskie złote' was significantly lower. The latest sowing date significantly reduced the AGB in each cultivar.

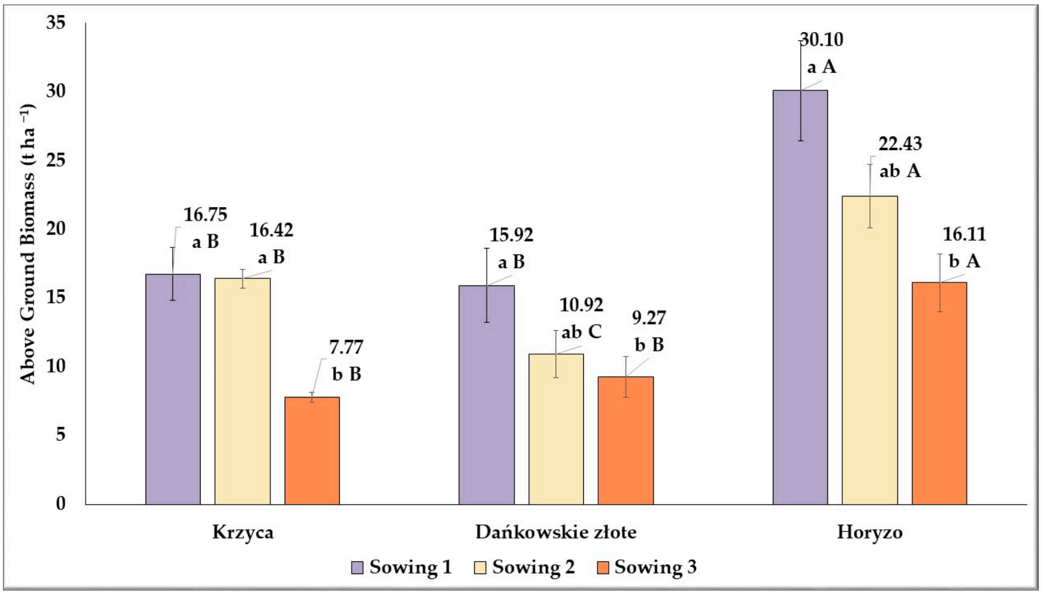


Figure 12. Effect of cultivar and sowing date on the AGB (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

3.2.9. Effect of Cultivar and Sowing Date on the Harvest Index

Differences were significant in the harvest indices between cultivars, whereas sowing date had less effect on it (Figure 13). The highest result was achieved for 'Dańkowskie złote' (38.41%), although significantly lower results were obtained only in 'Krzyca' at the first and second sowing dates (23.60% and 19.95%, respectively). The harvest index of 'Dańkowskie złote' and 'Horyzo' was not affected by sowing date, whereas it was significantly increased by the latest sowing date in 'Krzyca'.

3.3. Relationship between Variables and Ranking of Cultivars

A Pearson's correlation analysis was performed to analyze the relationships between the observed quantitative characteristics. The strongest significant positive correlation was detected between the grain yield and AGB (R^2 = 0.87). Tight correlations were observed between the grain yield and the number of grains per spike (R^2 = 0.72), between the spike length and AGB (R^2 = 0.71) and between the flag leaf area and AGB (R^2 = 0.70). We found medium and weak relationships between the number of spikes m^{-2}, TGW, HI and the spike parameters. In addition, there was a negative and weak correlation between the HI and AGB (R^2 = −0.26), but it was not significant. These results suggested that a higher rye plant and larger leaf area were related to favorable spike parameters and other yield structural elements. Moreover, an early sowing date also could be related to the high yield parameters, because significant negative relationships could be detected between the earliness of sowing date and yield parameters (spike number, spike length, grain yield and above ground biomass) (Table 7).

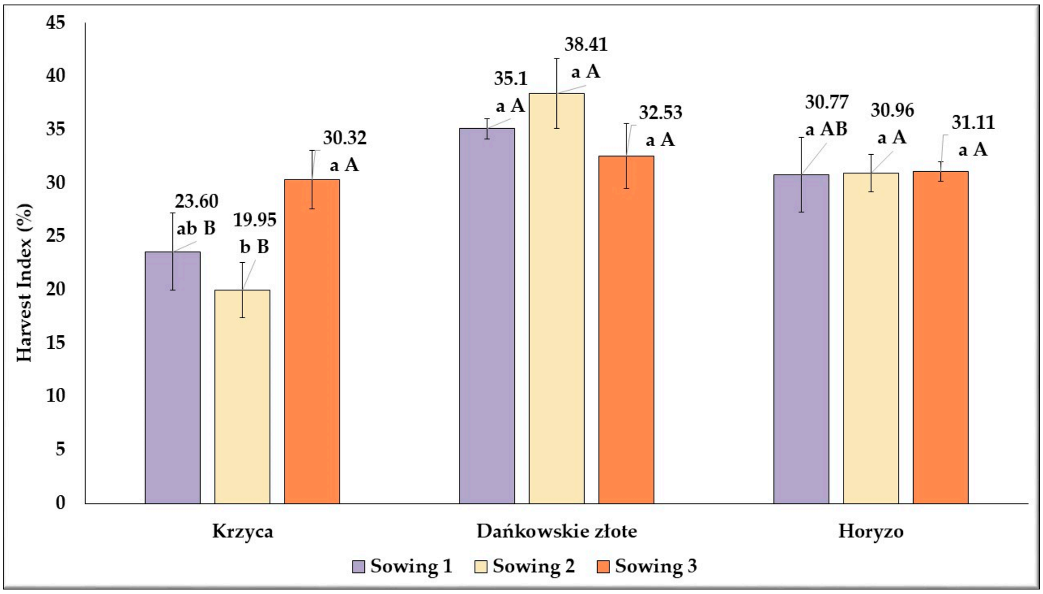


Figure 13. Effect of cultivar and sowing date on the harvest index (mean ± SE). Different lowercase letters indicate significant differences between the means of plots sown on different dates (within the same cultivar), whereas capital letters indicate significant differences between the means of cultivars within the same sowing date (LSD Post Hoc Test; $p < 0.05$).

Table 7. Correlations between variables and their relationships with sowing date. Abbreviations: DS: date of sowing; PH: plant height cm; FLA: flag leaf area cm^2; SN: spike number m^{-2}; GN: grain number $spike^{-1}$; SL: spike length; TGW: thousand-grain weight; GY: grain yield; AGB: above ground biomass; HI: harvest index.

	DS	PH	FLA	SN	GN	SL	TGW	GY	AGB	HI
DS	1.00									
PH	−0.22	1.00								
FLA	−0.31 *	0.64 **	1.00							
SN	−0.43 **	0.13	0.37 **	1.00						
GN	−0.25	0.66 **	0.63 **	0.21	1.00					
SL	−0.42 **	0.60 **	0.62 **	0.27	0.58 **	1.00				
TGW	0.03	0.32 *	0.20	−0.04	0.43 **	0.22	1.00			
GY	−0.43 **	0.67 **	0.67 **	0.53 **	0.72 **	0.69 **	0.45 **	1.00		
AGB	−0.50 **	0.65 **	0.70 **	0.56 **	0.52 **	0.71 **	0.38 **	0.87 **	1.00	
HI	0.08	0.06	0.04	−0.03	0.43 **	−0.05	0.11	0.22	−0.26	1.00

-1.0 -0.5 0.0 0.5 1.0

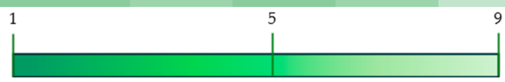
* Pearson correlation is significant at the 0.05 level, ** Pearson correlation is significant at the 0.01 level.

Treatment combinations (cultivar/sowing date) were ranked for all observed characteristics, and all treatment combinations were ranked according to the average of the characteristics ranking (Table 8). We found that the 'Horyzo' cultivar produced the best results, regardless of sowing date.

However, the best ranking was achieved by the cultivar 'Horyzo' sown on the earliest date (S1: November 01), followed by 'Horyzo' sown on the second sowing date (S2: November 15) and then 'Horyzo' sown on the latest day (S3: December 01). 'Krzyca' and 'Dańkowskie złote' sown on December 01 were in the last places in the ranking.

Table 8. Ranking of treatment combinations (cultivar/sowing date) according to all characteristics observed (PH: plant height; FLA: flag leaf area; SN: spike number m^{-2}; GN: grain number $spike^{-1}$; SL: spike length; TGW: thousand-grain weight; GY: grain yield, AGB: above ground biomass; HI: harvest index). 1: the best ranking position; 9: the worst position in the ranking.

Cultivar/Sowing Date	PH	FLA	SN	GN	SL	TGW	GY	AGB	HI	Mean
'Krzyca'/01 Nov.	6	5	5	5	3	7	6	3	8	5.3
'Krzyca'/15 Nov.	4	7	3	8	6	8	7	4	9	6.2
'Krzyca'/01 Dec.	5	8	9	9	8	5	9	9	7	7.7
'Dańkowskie złote'/01 Nov.	7	6	1	6	5	9	3	6	2	5.0
'Dańkowskie złote'/15 Nov.	8	4	6	4	7	4	5	7	1	5.1
'Dańkowskie złote'/01 Dec.	9	9	8	7	9	3	8	8	3	7.1
'Horyzo'/01 Nov.	1	1	2	2	1	1	1	1	6	1.8
'Horyzo'/15 Nov.	2	2	7	1	2	2	2	2	5	2.8
'Horyzo'/01 Dec.	3	3	4	3	4	6	4	5	4	4.0



4. Discussion

The aim of this study was to test winter rye cultivars sown on three dates in adaptation experiments to enhance the selection of the most suitable cultivar and the proper sowing date. Rye is mainly grown in unfavorable soil and in cool climate conditions (such as in northern Europe, eastern Siberia); therefore, in most cases, the goal of sowing date experiments is to increase survival during the winter period [49].

In regions where agricultural production is highly dependent on irrigation but the water supply is limited, it is necessary to choose the best sowing date. With a modified sowing date, we can use natural precipitation to the greatest extent, thus saving the most irrigation water while achieving the best possible yield [16]. In addition, optimal sowing dates are different in agro-climatic regions [49], and rye is not traditionally cultivated in Iraq; thus, adaptation experiments should be performed including cultivars and technological elements. We found that each observed characteristic was influenced by cultivar and sowing date.

4.1. Plant Height

Plant height is one of the important characteristics attributed to the growth and development of plants [50]. We also found a significant, positive relationship (r = 0.67) between plant height and grain yield. In our irrigated experiments, the plant height was influenced by cultivar but not by sowing date in the case of 'Krzyca' and 'Dańkowskie złote'. 'Horyzo' plants were the highest in both crop years, and plants grown on plots sowed on the latest date (01 December) were significantly shorter than those sown earlier. Similarly, in sowing date experiments performed in the Republic of Uzbekistan with 'Shirokolistnaya', the highest plants (155 cm) were found in plots sown on 01 October, whereas later sowing dates resulted in smaller plants (140 and 135 cm, measured in plots sown on 15 October and 01 November, respectively) [50]. Likewise, the significantly highest 'Aslım 95′ plants developed in the case of the earliest sowing (01 October) in Turkey, and the later the sowing was, the lower the plants developed [36]. In contrast, higher plants were observed in field experiments ('Paldanghomil') when sowing occurred in October compared with those sown in September in the Republic of Korea [51].

4.2. Grain Yield, and Yield Structural Elements

The grain yield of rye may be highly variable between cultivars. However, when determining the yield of rye cultivars, the purpose of cultivation (i.e., grain yield, dry matter yield, methane yield, etc.) must also be considered [24,52]. The rye cultivars were tested in two-year field experiments, with the aim of producing grain yield, which would be used as human food or as animal feed. The grain yield of rye may be significantly influenced by crop year, due to variations in temperature and precipitation amounts, as was reported for north European conditions (Germany) [53]. In our study, performed in the south Iraq region in two crop years, resulted in very similar grain yields in all cultivars and for each sowing date.

4.3. Effect of Sowing Date on Yield Characteristics

Delaying the sowing date by one day resulted in a decrease in the grain yield by 1% in winter wheat in China [54]. We also found that the majority of traits were influenced by sowing date in rye: in general, the best results were achieved when the earliest sowing date was applied (01 November). For the average of each cultivar, the plant height, flag leaf area, number of grains per spike and length of spike were significantly decreased when sowing was performed at the latest date (01 December), compared to both earlier sowing dates. Moreover, both the grain yield and above ground biomass decreased significantly as the sowing date was delayed. In contrast, the TGW and HI were less influenced by sowing date.

A similar tendency was found when sowing date experiments were performed in the Republic of Uzbekistan with 'Shirokolistnaya'. The highest grain yield (5.3 t ha^{-1}) was found on plots sown on 01 October, whereas later sowing dates resulted in lower yields (4.91 and 4.17 t ha^{-1}), harvested from plots sown on 15 October and 01 November, respectively [50]. In field experiments in Turkey including the 'Aslım 95′ cultivar, it was also found that grain yield tended to decrease with a later sowing date [36]. The seeds were sown at five time points between 01 October and 01 December, and the significantly highest grain yield was harvested when sowing occurred on 15 October. The yield was lower when sowing was performed earlier (01 October) or later [36]. The opposite tendencies could be observed when seeds were sown on 20 or 30 September and 20 October (in the Republic of Korea): the later the sowing was, the greater was the quantity of both the fresh and dry yield [51]. Sowings were performed on 03 May, 25 May and 07 June in field experiments in Brazil. Considering the yield, the 'Teprano' cultivar preferred the early sowing (1.09, 0.8 and 0.28 t ha^{-1} were harvested from plots sown on 03 May, 25 May and 07 June), but 'BRS Progresso' seemed to be stable, as its yield was not influenced by sowing date (harvested yields were 1.59, 1.53 and 1.53 t ha^{-1}, respectively) [55]. Traditional cultivars tested in Kentucky (USA) produced on average 2.22, 2.11 and 2.02 t ha^{-1} grain yield from early, intermediate and late sowing dates [35]. These yields were lower than those harvested in our experiments from plots sown on 01 November, 15 November, and 01 December ('Krzyca': 3.75, 3.24 and 2.34; 'Dańkowskie złote': 5.53, 3.95 and 3.18; 'Horyzo': 8.82, 6.81 and 5.08 t ha^{-1}, respectively) Although sowing date (middle and end of September) hardly affected the grain yield in Germany, an interaction could be observed between the sowing date and seeding rate, which was dependent on the cultivar [53]. Two cultivars ('Ducato' and 'Recrut') required higher seeding rates to obtain the same yield when they were sown in late September compared to the earlier sowing date, but this was not true for the hybrid 'Brasetto' [53].

The sowing date may also significantly affect the structural yield elements of cereals, which ultimately contribute to the total yield [55]. For example, the number of spikes m^{-2} and the number of grains per spike were considerably influenced by the sowing date in the case of 'Aslım 95′. This cultivar responded with a higher number of grains per spike to earlier sowing [36]. In addition, a delayed sowing date led to a decreased TGW in 'Aslım 95′ [36].

4.4. Interaction between Cultivars and Sowing Date

Rye cultivars are specifically capable of compensating for losses occurring during unfavorable periods of the growing season, e.g., few stems due to improper sowing date.

Therefore, all new rye cultivars should be included in the experiment to find the optimal sowing date to maximize their genetic potential [53]. For example, the hybrid rye 'Brasetto' sown at the end of September produced fewer tillers compared to plants sown in the middle of September. However, the number of grains increased significantly in the case of late sowing; thus, the yield was ultimately higher [53].

We also found that the responses of cultivars were various. The sowing date significantly affected the plant height only in 'Horyzo' and the flag leaf area and the number of grains per spike in 'Krzyca'. The length of the spike was not significantly influenced by sowing date in any cultivar. The number of spikes m^{-2} was enhanced by earlier sowing dates, but differences were not significant in 'Horyzo'. In contrast, the TGW increased in 'Dańkowskie złote' but decreased in 'Horyzo' as the sowing date was delayed, whereas it was not altered in 'Krzyca'. Since irrigation was applied at the same time for all experimental plots and differences between the early growth vigor of cultivars could have resulted in different phenological states at the same time, the reason for the opposite responses may thus be the difference between the water supply during the grain filling stage for the different genotypes. Considering the performance of the cultivars, we found that for the average of each sowing date, the grain yield of 'Horyzo' was significantly higher (6.9 t ha^{-1}) than those of 'Krzyca' and 'Dańkowskie złote' (3.1 and 4.2 t ha^{-1}, respectively). 'Horyzo' was selected because of its high yield capacity and because this cultivar also proved its good productivity in our experiments. In addition to its good adaptability, the 'Dańkowskie Złote' cultivar was involved because of a good yield stability between crop years was experienced earlier in experiments in Hungary [46]. Even if this cultivar did not produce a high grain yield in our experiment, and two years is not enough to declare that 'Dańkowskie złote' stably produces this yield, the results so far are encouraging. This cultivar has much more genetic potential, considering its TGW, which was much higher (38.6 g) in European environments (Hungary, United Kingdom, Poland and France) [46] than in our study (maximum 27.6 g). Although the grain yield of 'Krzyca' was the lowest in this experiment, further study is necessary because it produced the highest above ground biomass (18.45 t ha^{-1} as the average for seeding rates) in other experiments in Iraq [33].

4.5. Correlations between Studied Variables and Their Relationship with Sowing Date

A negative correlation could be detected between the sowing date and the studied characteristics (except for TGW), which means that the later the sowing is, the smaller the result obtained for the given trait. These relationships were significant in the case of flag leaf area, number of spikes per m^2, length of spike, grain yield and above ground biomass. The grain yield showed significant positive correlations primarily with the AGB, followed by the number of grains per spike and spike length. Even though the "*r*" values were lower, the plant height, flag leaf area, number of spikes and TGW also could be related significantly to the grain yield.

Similar relationships were reported between the yield and both the number of spikes per m^2 and number of grains per spike when 16 winter rye cultivars were grown under water-limited conditions during drought experiments in Germany [28]. They also found that the TGW showed a positive relationship with grain yield, only when drought appeared during the grain filling stage. In contrast, when rye cultivars were grown in well-watered conditions, these relationships were only detectable in a given crop year [28]. Summarizing their results obtained from two-crop-year experiments, they concluded that the number of spikes m^{-2} and grains per spike are of great importance in the crop yield quantity under drought stress. Although we supplied the water demand with irrigation when it was needed, we also detected a very similar relationship.

When German researchers processed experimental data of 26 years of value for cultivation or use (VCU), they found that the grain yield was highly correlated with the number of spikes m^{-2} in the case of hybrid rye cultivars. In contrast, the TGW and the number of grains per spike had the strongest correlations with yield in the case of population cultivars [56]. In a long-term crop rotation experiment on sandy soil (established by Vilmos

Westsik in 1929 in Hungary), the grain yield of rye was highly correlated with TGW, which was significantly influenced by the humus content of soil [57]. In addition to sowing date, other factors (seeding density, different temperature characteristics, nutrient supply, water deficit and so on) may also influence the yield structural elements [56,57], and some of them would be worth studying in the future to optimize the cultivation method of rye in the agro-climatic conditions of Iraq.

5. Conclusions

We can conclude that all the tested rye cultivars can be grown safely under the agro-climatic and soil conditions of the southwestern part of Iraq. However, comparing cultivars, the best results were achieved by the 'Horyzo' cultivar (grain yield was 6.9 t ha^{-1} on average for the three sowing dates). Moreover, the highest yield result (8.82 t ha^{-1}) was produced when it was sown on 01 November. The cultivar showed the most significant influence on the agronomic traits observed, followed by the cultivar-specific effects of sowing date. However, we could not detect any crop year effect. Based on the results of this study, we recommend cultivation of 'Horyzo' sown at the beginning of November. Further research needs to be done to optimize the cultivation technology (for example, nutrient supply), including more cultivars.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14091995/s1, Table S1. Results of Two-Way ANOVA variance test for all studied traits; Table S2. Analysis of variance test: effect of cultivars; Table S3. LSD Post Hoc test: effect of cultivars; Table S4. Analysis of variance test: effect of sowing dates. Table S5. LSD Post Hoc test: effect of sowing dates.

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