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The Response of Promising Winter Rapeseed Lines to Delayed Cultivation

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ABSTRACT

Some promising winter rapeseed lines were tested for their response to delayed cultivation. Accordingly, an experiment based on a split-plot design arranged in a randomized complete block design was applied during two cropping seasons (2020-2021 and 2021-2022) at the Research Station of Mahidasht, Kermanshah. Two Sowing dates September 20th and October 14th, along with 12 rapeseed genotypes were considered as main and sub-factors, respectively. Different agro-morphologic features including days to initiation of flowering, days to the end of flowering, days to physiological maturity, flowering duration, pod numbers per plant, plant height, seed per pod, sub-branches numbers, 1000-seed weight, and finally the grain yield have been measured. The results of two years of combined variance analysis showed a significant effect for the year regarding all evaluated traits, except for the sub-branch number. In the first and second years, the grain yield of rapeseed lines was equal to 3030 and 1661 kg ha^{-1}, respectively. Combined analysis of variance results indicated that the sowing date × year interaction effect was significant for grain yield; therefore, the climatic conditions affected the response of rapeseed lines to the delayed sowing date. Also, significant effect was observed for sowing date regarding all investigated traits was significant, except for the seed numbers per pod. The rapeseed lines showed significant differences for pod numbers per plant, 1000-seed weight, plant height, sub-branch number, and grain yield. The results have also indicated a non-significant effect for genotype × sowing date interaction for grain yield. Therefore, the investigated lines did not show a different response to altered levels of sowing dates, and the lines that performed well under normal sowing date conditions performed well under delayed sowing date conditions as well. The highest grain yield was observed in Line No. 4 (WRL-17-98) with 3496 and 2162 kg ha^{-1} in normal and delayed sowing dates, respectively.

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1. Introduction

Oilseeds play a central part in ensuring the food security of human societies, and researchers in the agricultural sector, both inside and outside Iran, have always paid special attention to them (Mokhtassi-Bidgoli *et al.*, 2022). Currently, only 10-15% of the country's oil needs are met through the production of oilseeds domestically. Therefore, the expansion of the cultivated area for oilseeds in Iran is of great importance. Rapeseed is one of the oilseeds that can be cultivated in various climates of Iran due to its adaptability (Rostami Ahmadvandi and Faghihi, 2021). Currently, the highest amount of rapeseed production occurs in the humid, warm regions of northern Iran, where spring rapeseed varieties are predominantly cultivated (Shafighi *et al.*, 2021). However, the cold and mid-cold climates of the country have high potential for increasing the cultivation of winter canola varieties (Faraji *et al.*, 2009). One of the limitations of rapeseed cultivation in these regions is its sensitivity to the sowing date. The optimal sowing date for oilseed rape can vary widely depending on the region, climatic conditions, and site-specific factors (Pullens *et al.*, 2019). Balodis and Gaile (2012) found that the sowing date significantly influenced plant development in autumn. Earlier sowing dates led to greater growth

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point height, root neck diameter, plant and root mass, and main root length, along with increased growing degree days (GDD) (Sieling *et al.*, 2017). However, for various reasons, farmers sometimes sow rapeseed late. Delayed sowing of rapeseed results in reduced yield. It is reported that for every week of delay in sowing rapeseed in Australia, grain yield decreases by 5-12% (Kirkegaard *et al.*, 2016). Therefore, it is necessary to identify rapeseed genotypes that tolerate delayed cultivation. Although many scientific references emphasize the reduction in rapeseed yield under delayed cultivation, the identification and use of genotypes tolerant to delayed sowing can significantly contribute to increasing the cultivated area of rapeseed in cold and mid-cold regions of Iran (Hu *et al.*, 2017).

Among all aspects of crop management, sowing date is the most variable and is often the determining factor for success in crop production (Fanaei *et al.*, 2015). Studying the effects of different temperature regimes, caused by varying sowing dates, on plant growth and improving tolerance to winter cold in crops is of great importance (Nahar *et al.*, 2015). In the study by Zareei Siahbidi et al. (2020), the average seed yield of 33 rapeseed genotypes decreased by 17% due to a delay in the sowing date from September 28th to October 7th. However, the results indicated a reduction in the extent of yield regarding the delayed cultivation depending on climatic conditions in autumn. In Eslam (2011) study, delaying the sowing of rapeseed from September 11th to October 20th significantly reduced grain yield and its components. In this study, sowing date by variety interaction showed no significant effect for any of the measured features; as a result, the cultivars studied showed a similar response to delayed sowing. In the study by Noori et al. (2019), the pod number per plant and the 1000-seed weight of rapeseed sown on the delayed sowing date (October 26th) significantly decreased compared to the usual sowing date (October 11th). In the study by Zareei Siahbidi et al. (2020), the results showed reduced grain yield in response to the planting delayed date in both experimental cropping seasons (34.4% and 29.85% reduction). This reduction was attributed to the late planting date impact which affected the yield components including the pod numbers per plant as the most significant contributor to the grain yield components in this plant (decreased by 32.7% and 30.2% in the first and second years, respectively). An earlier sowing date for rapeseed can also increase productivity and reduce the economic risk associated with rapeseed cultivation (Brill *et al.*, 2016). Safdari-Monfared et al. (2019) stated that proline content along with carbohydrate levels in the plants improved in early cultivation (October 7th) compared with late cultivation (October 27th). In this study, use of glycine betaine (GB) to gather with early sowing had positively influenced both the quantity and quality of rapeseed oil. In a study carrying out for three consecutive years, delayed sowing date significantly reduced the accumulation of above-ground and tap root dry matter, as well as the growth area index (GAI) of oilseed rape by the end of autumn (Sieling *et al.*, 2017). Furthermore, Sieling et al. (2017) noted that the decrease in the dry matter of the tap section of root was more significant than the decrease in above-ground dry matter.

Despite the fact that the most suitable sowing dates for rapeseed have been determined for the cold and mid-cold regions of Iran, farmers in these regions sometimes plant rapeseed late for various reasons. One major reason for the delay is the reduction of water resources for irrigating rapeseed at the start of the cropping season. Therefore, it is essential to identify rapeseed cultivars that exhibit rapid early growth and produce high seed yields, even under delayed sowing conditions. In this research, the objective was to identify the most suitable rapeseed genotypes for delayed sowing while investigating the impact of delayed cultivation on key agronomic traits of rapeseed.

2. Materials and methods

To consider the promising winter rapeseed lines responses to delayed sowing, a split-plot design arranged based on randomized complete block design (RCBD) was carried out over two consecutive cropping years (2020-2021 and 2021-2022) with three replications at the Mahidasht Agricultural Education Center research farm (Kermanshah). Sowing dates, including normal and delayed sowing, were considered the main factors and 12 rapeseed genotypes were evaluated as sub-factors. The normal sowing date was September 20, and the delayed sowing date was October 14. Each experimental plot was comprised of 6 rows with 20 cm space between rows and 4 meters long, and plant density of 50-60 plants per square meter. Soil properties and the information regarding climatic conditions of the cultivation sites are presented in Tables 1 and 2, respectively. In this experiment, 10 elite genotypes along with 2 local genotypes were included as sub-plots their information related to their origin, growth habit, and code numbers are presented in Table 3. Seedbeds were prepared in September using a plow instrument along with disc harrow and leveler, followed by the seeding of the experimental plots in October. Soil tests (Table 1) were conducted to assess crop nutrition needs, leading to the application of potassium (100 kg ha^{-1} Potassium sulfate) and phosphorus (150 kg ha^{-1} Triple superphosphates) fertilizers during seedbed preparation. Nitrogen fertilizer was applied in three phases including 100 kg ha^{-1} urea during seedbed preparation, 150 kg ha^{-1} urea at the stem elongation stage and 100 kg ha^{-1} urea just before the flowering stage. Super Galant (HaloxyFop–RMethylEster) herbicide was utilized to manage narrow-leaved weeds and Confidor (Imidaclopride SC35%) pesticide was used for controlling aphids. The experiment was irrigated four times during spring, each of which contained 550 to 600 square meters of irrigation water. Various traits were measured, including the days to the start and end of flowering, physiological maturity, flowering duration, plant height, number of pods per plant, seeds per pod, and sub-branches. Grain yield was calculated by harvesting 3.2 m^2 from the central rows of each plot at maturity. Data analysis was performed using SAS software (Spector, 2003) for a combined analysis of variance, with mean comparisons conducted via the Least Significant Differences (LSD) test.

Table 1. Physico-chemical properties of soil at Mahidasht site.

Phosphor (ppm)	Potassium (ppm)	PH	Organic Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Soil Texture
24	450	7.86	1.15	7	43	45	Clay-silt

Table 2. Climatic conditions of Mahidasht Agricultural Research Station during cropping seasons 2020-2021 and 2021-2022

Months	2020-2021					2021-2122				
	Temperature (°C)				Precipitation (mm)	Temperature (°C)				Precipitation (mm)
	Minimum	Maximum	Mean	Long Time		Minimum	Maximum	Mean	Long Time	
September-October	2.0	34.8	19	18.1	0.8	4.3	34.2	19.2	18.1	0.0
October-November	1.2	28.6	13.6	11.3	45.3	-1.2	26.9	12.1	11.4	41.8
November-December	-3.1	16.6	6.9	5.5	131.9	-3.2	19	8.4	5.5	34.4
December-January	-9.1	12.2	4.3	2.6	7.8	-11.3	16	4.2	2.6	27.6
January-February	-8.2	21.0	6.4	2.6	93.6	12.3	16.8	3.4	2.6	28.7
February- March	-5.5	23.0	7.9	6.7	21.7	-6.4	20.4	8.8	6.7	60.9
March-April	-2.4	30.0	13.8	11.2	3.9	-3.0	30.1	14.2	11.2	10.4
April-May	5.5	36.3	20.5	16	7.5	5.4	32.6	17.5	16.41	81.6
May-June	9.8	42.3	24.3	22.1	00.0	8.6	40.4	24.6	22.1	00.0

Table 3. Growth type and origin of investigated rapeseed lines/varieties

Number	Line/Variety	Origin	Growth Type
1	WRL-04-95*	Iran	Winter
2	WRL-05-96	Iran	Winter
3	WRL-06-97	Iran	Winter
4	WRL-17-98	Iran	Winter
5	WRL-19-99	Iran	Winter
6	WRL-21-100	Iran	Winter
7	WRL-28-101	Iran	Winter
8	WRL-30-102	Iran	Winter
9	WRL-34-103	Iran	Winter
10	WRL-35-104	Iran	Winter
11	Nafis	Iran	Winter
12	Nima	Iran	Winter

*The seeds were provided by the ARREO center from its main section in Karaj, Iran.

3. Results and discussion

Prior to the combined analysis of variance (combined ANOVA), the test of normality and variance homogeneity for both years was carried out. The result of this analysis indicated that residuals of the linear model of combined ANOVA were normally distributed because the probability values for all measured features were greater than 0.065, $p>0.065$ in comparison to the significant probability limit of $p<0.05$. Additionally, there result of the homogeneity test showed that the probability of variance comparison between the two environments (years) based on Bartlett's test was not significant for the residuals related to each measured trait. According to the results of combined ANOVA, the main effect of year for all evaluated traits including grain yield, number of branches, 1000-seed weight, seed per silique, silique per plant, plant height, days to maturity, duration of flowering period, days to end of flowering, and days to initial flowering, was significant, except the sub-branches number (Table 4). Temperature fluctuations in the second year influenced the phenology of rapeseed genotypes. Due to climatic changes, days to the flowering of rapeseed lines were extended in both sowing dates during the second year compared to the first year. In the first experimental year, the average of days number to the start of flowering for the 12 rapeseed genotypes was 183 and 173 for the normal and delayed sowing dates, respectively, while in the second year, it increased to 196 and 183 days, respectively (Table 5). Gabrielle et al. (1998) state that air temperature is the main factor influencing the duration of the growth period from germination to mid-flowering. When other environmental conditions are optimal, higher temperatures speed up the phenological processes from germination to flowering (Bhattacharya, 2022; Springate and Kover, 2014). The changes in the phenology of rapeseed lines caused significant differences in the average grain yield between the first and second years. The grain yield of the 12 rapeseed genotypes was 3030 kg ha^{-1} in the first experimental year while it was equal to 1661 kg ha^{-1} in the second experimental year. The environmental conditions normally represent a large variation in the grain yield along with the quality of rapeseed (Rathke *et al.*, 2005) and other crops (Saed-Moucheshi *et al.*, 2021; Sohrabi *et al.*, 2024).

Table 4. Combined analysis of variance for agronomic traits of rapeseed lines/variety

Source of variation	D.F.	Mean of squares: Days to initial flowering	Days to end of flowering	Duration of flowering period	Days to maturity	Plant height	Silique per plant	Seed per silique	1000-seed weight	Number of branches	Grain yield
Y	1	2765**	69.4	1958.1**	2925**	3490.8	43160.1**	64.67*	115.69**	22.56	67527306**
Rep (Year)	4	22.3	44.7	18.5	92	809.1	278.7	7.83	3.28	5.93	1290573
S*	1	7496.7**	9280.1**	95.1**	15026.7**	16490.8*	10217.8**	254.67	16.11**	91.84**	43663461*
Y×S	1	70.8**	330*	95.1*	751.7**	105.1	0.3**	0.02	5.08**	0.01	1171445**
SD×Rep (Y)	4	3.4	28.7	22.9	38.2	1577	400.9	13.66	0.97	0.19	4281411
V	11	10.2	0.4	12.5	99.4	420.9**	1657.7**	2.49	1.81*	2.52**	1118566**
S×V	11	8.4**	1.3	11.9**	84.8	70.7	71.4**	5.79*	0.56	0.84*	179032
Y×V	11	8.2**	0.8	11.3**	95.4	52.2	209.3**	3.9	0.53	0.35	180219
Y×S×V	11	13.1**	2.9	6.3**	115.3	97.8	46.2**	1.58	0.97	0.31	81167
Error	88	2.93	1.79	2.84	20.9	71.9	18.97	2.94	0.07	0.50	163602
C.V. (%)		0.92	0.62	5.57	1.84	6.84	3.6	8.8	7.85	3.73	17.24

*: Y=Year, Rep=Replication, SD=Sowing Date, V=Variety

Table 5. Agronomic traits mean for rapeseed lines in normal and delayed sowing dates during the 2020-2021 and 2021-2022 cropping seasons.

Year	Sowing date	Days to initial flowering	Days to end of flowering	Duration of flowering period	Days to maturity	Seed per silique	1000-seed weight (g)	Grain yield (kg ha^{-1})
2020-2021	Normal sowing date (September 20)	188	224	36	256	20	4.4	3671
	Delayed sowing date (October 14)	173	205	32	231	18	4.1	2390
Change (%)		7.97	8.4	11	9.8	10	6.8	34.9
2021-2022	Normal sowing date (September 20)	196	222	27	260	22	2.96	2121
	Delayed sowing date (October 14)	183	209	27	244	19	1.9	1200
Change (%)		6.6	5.8	1	6.1	13.6	35.8	43.4
LSD ($p \leq 0.05$)		0.8	2.3	2.1	2.7	1.6	0.43	899

The differences in the grain yield and its components across different years have also been reported in other studies. For instance, in a study conducted by Zareei Siahbidi et al. (2020), the effect of the year (climate) on phenology along with the grain yield and yield components was significant. The 1000-seed weight, the siliques numbers per plant, and the seeds number per pod in the first year were respectively equal to 3.8 grams, 20.7, and 237. In the second year, these values dropped to 173, 16.8, and 3.3 grams, respectively. Besides climatic conditions, the presence of Broomrape in the second year contributed to the significant reduction in grain yield and its components. The threat of Broomrape weed in rapeseed and other crops belonging to the Brassica genus is severe, causing yield losses of up to 100% in subtropical regions (Jat and Singh, 2018).

The results of the two-year combined variance analysis (Table 4) showed that the effect of sowing date on all investigated traits was significant, excluding the seeds number per silique. The interaction effect of sowing date × year was significantly related to all agronomic traits, except for plant height, seeds per silique, and the branches number. Additionally, data comparison revealed that the days number from sowing to the flowering and the physiological maturity decreased significantly with delayed sowing, by 7.9% and 9.8% in the first year, and by 6.6% and 6.1% in the second year, respectively. Therefore, the decrease in days to flowering and maturity in delayed sowing was also influenced by the year. Overall, delayed sowing resulted in a shortened pre-flowering period, and the duration between flowering and maturity was reduced as well (Table 6).

The mean comparison of data showed that delayed sowing triggered a significant drop in the yield and its components in both years (Table 6). Rapeseed plants sown later are more susceptible to stress factors such as extreme temperatures, frost, and excessive rainfall during winter for their inconvenient growth and limited rosette period, terminal drought stress due to elongated required days to physiological raping, and nutrient uptake limitations as the results of poorly developed root systems, according to (Liu *et al*., 2022) Most of the investigated traits in the study of Dolatparast et al. (2021) and Ranabhat et al. (2021) were affected by the sowing date. Results of the study conducted by Ranabhat et al. (2021) showed that the grain yield reduction due to delayed sowing was equal to 35% and 43% in the first and the second experimental seasons, respectively. In the first experimental year, the reduction in the siliques number per plant, the seeds number per pod, and the 1000-seed weight was 11%, 15%, and 6.6%, respectively, while in the second experimental year, the mentioned values were equal to 15%, 12.5%, and 35%, respectively.

In different years, the reduction in grain yield and its components due to delayed sowing varies and is largely dependent on climatic conditions, particularly air temperature during autumn, which strongly influences overwintering. In the study by Zareei Siahbidi et al. (2020), seed yield decreased by 24.4% and 38.9% due to delayed sowing in the first and second years, respectively. The siliques number per plant, as the most significant yield component, decreased by 7.23% and 3.21%, respectively. Similarly, Brill et al. (2016) and Khalatbari et al. (2022) found varying results when examining different planting dates over three years, with the differences attributed to climatic conditions. Mendham et al. (1981) investigated the effect of delayed planting and climate on winter rapeseed across seven cropping seasons and found that the response of rapeseed genotypes varied based on climatic conditions.

Table 6. Average agronomic traits of rapeseed lines/variety under normal and delayed sowing date.

Sowing date	Days to initial flowering	Days to end of flowering	Duration of flowering period	Days to maturity	Plant height (cm)	Silique per plant	Seed per silique	1000-seed weight (g)	Number of branches	Grain yield (kg ha^{-1})
Normal sowing date (September 20)	192	223	31	258	134.5	129	20.8	3.67	5.9	2896
Delayed Sowing Date (October 14)	178	207	29.5	238	113.1	112	18.2	3.00	4.4	1796
Change (%)	7.3	7.2	4.8	7.7	15.9	13.2	12.5	18.2	25.4	37.98

The combined analysis of variance results indicated significant differences among rapeseed lines for pod numbers per plant, plant height, the thousand-seed weight, number of sub-branches, and grain yield. Nevertheless, the genotype by sowing date interaction effect was not significant for grain yield. This suggests that the genotypes did not show a distinct response to the different sowing dates. The lines that performed well under normal sowing conditions also performed well under delayed sowing conditions. Thus, selecting high-yielding genotypes for normal sowing can also identify suitable lines for delayed sowing, as their performance remains consistent across different planting times (Table 7). Line No. 4 (WRL-17-98) had the highest grain yield, producing 3496 kg ha^{-1} under normal sowing and 2162 kg ha^{-1} under delayed sowing. In contrast, Line No. 1 (WRL-04-95) had the lowest yield, with 1888 kg ha^{-1} and 1428 kg ha^{-1}, respectively, under the two sowing dates. The Nima cultivar, an Iranian open-pollinated variety, yielded 3150 kg ha^{-1} and 2155 kg ha^{-1} under normal and delayed sowing, respectively. High-yielding lines like Nima and Line No. 4 (WRL-17-98) shared certain traits that set them apart from other lines. Both had the longest days to maturity and the greatest plant height, which contributed to their higher siliques number per plant. The difference in plant height among genotypes was partly explained by differences in their days to maturity. The siliques number per plant is a key yield component, as siliques contain seeds and contribute to seed growth during the early stages of seed filling through photosynthesis. Scott et al. (1973) found that reduced yields in late sowing were primarily due to fewer pods per unit area and lower seed weight. Similarly, Khayyat and Gohari (2006) and Shafighi et al. (2021) reported that the superior performance of certain cultivars could be attributed to genetic traits including higher yield potential, early maturity, and environmentally efficient use, along with strong physiological and phenological characteristics.

Table 7. Average of agronomic traits for rapeseed lines/variety under normal and delayed sowing date

Line /Variety	Days to initial flowering		Duration of flowering period		Silique per plant		Seed per silique		Number of branches	
	Swing Date									
	September 20	October 14	September 20	October 14	September 20	October 14	September 20	October 14	September 20	October 14
WRL-04-95	189	178	35	29	111	97	22	17	4	4
WRL-05-96	191	177	33	30	124	110	21	19	6	4
WRL-06-97	191	178	33	30	115	93	20	20	6	4
WRL-17-98	195	178	29	30	147	126	21	19	6	5
WRL-19-99	193	178	31	30	125	110	21	19	6	4
WRL-21-100	194	179	31	28	148	124	21	18	6	5
WRL-28-101	193	178	30	29	124	107	22	17	6	4
WRL-30-102	192	177	31	30	143	125	21	18	7	5
WRL-34-103	193	178	31	29	129	109	21	19	6	4
WRL-35-104	193	178	30	30	124	110	21	20	6	5
Nafis	191	178	32	30	117	112	21	16	6	4
Nima	194	178	28	30	144	126	21	17	7	5
LSD ($p \leq 0.05$)	3.47	3.47	2.4	2.4	6.5	6.5	1.2	1.2	0.53	0.53

4. Conclusion

Overall, the study demonstrated that the delayed sowing was able to make a change on yield components; and rapeseed phenology were heavily influenced by climatic conditions in autumn and winter. Changes in yield components in delayed sowing date caused a large change in grain yield, and the contribution of thousand grain weight to the reduction in grain yield in delayed cultivation was greater than the number of silique per plant and the number of seeds per silique. Importantly, genotypes that performed well under normal sowing also excelled under delayed sowing, suggesting that selecting high-yielding lines for normal sowing could also identify high-yielding lines for delayed sowing.

Conflict of interests

The authors declare no conflict of interest.

Ethics approval and consent to participate

No humans or animals were used in the present research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

All authors read the final version of this manuscript and approved it for publication in this journal.

Availability of data and material

The authors declare that they embedded all required data in the manuscript.

Authors' contributions

A. R. has prepared the experimental design and contributed to data collecting along with writing the manuscript. A. S. and A. Z. contributed to data collecting, and A. S. contributed to writing and preparing the manuscript.

Informed consent

The authors declare not to use any patients in this research.

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