Research Article

Evaluation of Climate-Resilient Wheat Lines for Yield-Related Traits Under Different Sowing Dates

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Abstract | Climate change has significantly reduced wheat production, while practicing wheat sowing at flexible dates can alleviate this impact on its output. This study aimed to determine the optimal sowing time of eleven (11) wheat genotypes under different climatic conditions. These 11 wheat genotypes, including 8 lines (PR-149, PR-152, PR-153, PR-154, PR-155, PR-156, PR-157, PR-158) and 3 controls (Khaista-17, Gulzar-19, Pirsabak-19), were sown at 3 different dates, i.e., 15th October, 15th November, and 15th December, in a field trial in a Randomised Complete Block Design (RCBD). Different agro-morphological traits were recorded, including emergence of heading, days to maturity, plant height, peduncle length, flag leaf area, tiller/m^2, spike length, spikelets/spike, spike weight, grain/spike, thousand-grain weight, grain yield, bundle yield, and harvest index. Analysis of variance (ANOVA) for genotypes and genotype-by-environment interactions was highly significant for all parameters. The genotype PR-149 produced the highest number of tillers/m^2 (292.7) in November planting, while October-sown genotypes produced the highest number of grains per spike for line PR-152 (75.4) and thousand-grain weight (46.7 g) for line PR-158. Grain yield was higher in November planting as cultivar Pirsabak-19 produced the highest yield (5042.2 Kg/ha). The 15th of November planting showed a prominent result, as it was the best-performing date for genotypes, while the 15th of December sowing produced the minimum yield.

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Introduction

A significant cereal crop in the *Poaceae* family is wheat (*Triticum aestivum* L.) (Petersen *et al*., 2006). *Triticum aestivum* is a hexaploid with 42 chromosomes and often self-fertilises (Sabit *et al*., 2024). Compared to other grains, wheat has more nutrients and provides energy for the body. Rich in fat, protein, dietary fiber, sugar, and carbohydrates. Except for lysine, the grain has high levels of vital amino acids, minerals, and vitamins (Rehman *et al*., 2017). Wheat provides 21% of total calories and protein, as the requirement for wheat in every emerging nation is increasing annually by 1%, every developing nation is trying to introduce new and better wheat stable varieties to replace the old ones (Shiferaw *et al*., 2013). Climate change has become the main issue for Pakistan. In the last few decades, severe floods, droughts, and storms have greatly affected Pakistan (Shah *et al*., 2024).

The major parameters in wheat grain production are significant yield constituents such as grains/spike, tillers/m^2, and 1000-grain weight (Akram *et al*., 2008; Zarghoona *et al*., 2025). Planting seasons, like many other factors, bring change in grain yield and many other parameters. Seven processed lines of wheat and three checks were grown in an experiment to compare their yield performance at different time of planting by giving a plant 15 days interval, the study concluded that the most favorable timing to seed is between October 15 and November 15, as delayed sowing begins to decrease the yield performance of the genotypes under late sowing (Rauf *et al*., 2023).

Research was conducted on three sowing dates, 1st, 15^{th,} and 30th December; the interaction between sowing dates and varieties showed no significance. The result showed that it was preferable to seed wheat on December 1st, the ideal date, as opposed to December 30th, the delayed date (Tahir *et al*., 2009). An experiment performed at the agronomy field laboratory in Bangladesh showed that sowing dates affect all the parameters significantly and revealed that mid-November sowing produces high yield (Madhu *et al*., 2018). Another study conducted at three different locations across Khyber Pakhtunkhwa (KP) for ANOVA and stability analysis revealed significant genotype (G), location (L), and genotype-by-environment interaction (GEI) effects for most traits, except grain weight per spike. Six (6) genotypes out of sixteen (16) were stable across all three locations; all the genotypes performed better at CCRI.

The relationship between grain yield and all traits except days to heading showed a positive correlation, indicating the effects of environmental variation on selecting adaptable genotypes (Khan *et al*., 2023). Hybrid wheat cultivars produced the highest grain yield across two-year field trials, outperforming the local varieties of the area in both early sowing and late sowing (Anjum *et al*., 2021; Rauf *et al*., 2023). Grain per spike and thousand grain weight were non-significant in sowing dates between 15th November and 25th December in Peshawar, with a ten-day interval. Genotypes performed better in November in contrast to December sowing (Awan *et al*., 2017). The current research evaluates the climatic resilience of wheat genotypes through their performance, and the study also measures the potential yield responses under different sowing dates.

Materials and Methods

The research study was conducted using a Randomized Complete Block design (RCBD) to evaluate the performance of the eleven (11) diverse wheat genotypes (8 PR lines + 3 Control) (Table 1). The genotypes were tested to assess their performances under three (3) different sowing/planting dates. Each genotype was evaluated as a separate, independent experiment, with a 30-day interval between each of the three planting dates: Early (October 15th), Normal (November 15th), and Late (December 15th). Each genotype was planted in four rows, each row being two meters long and spaced 30 cm apart. Recommended fertilizer (NPK) doses were applied accordingly.

Table 1: *Details of the varietal trial of 11 wheat genotypes.*

S. No.	Genotypes	Parentage
1	*PR-149*	BORL14*2/8/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/
2	*PR-152*	MERCATO/BECARD//BOKOTA
3	*PR-153*	BOKOTA/MUCUY//KUTZ
4	*PR-154*	BOKOTA*2/3/ND643/2*WBLL1//2*BAJ #1
5	*PR-155*	Inqilabi91/MEXICALE//SEHER06/3/IBWSN-101/PIRSABAK-05
6	*PR-156*	MUTUS*2/MUU//2*MUCUY
7	*PR-157*	TUKURU//BAV92/RAYON/3/DANPHE/4/DANPHE/5/WBLL1*2/ BRAMBLING*2//
8	*PR-158*	BORL14*2/8/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/
9	*Khaista-17*	KAUZ//ALTAR 84/AOS/3/MILAN/KAUZ/4/HUITES/7/ CAL/......
10	*Gulzar-19*	VORB/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR
11	*Pirsabak-19*	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/ KACHU/6/KAC

Data collection

Data was collected on (14) fourteen Different agro-morphological traits including emergence of heading, Days to maturity, plant height, peduncle length, flag leaf area, tillers/m^2, spike length, spikelet's/spike, spike weight, grain/spike, thousand-grain weight, grain yield, bundle yield and Harvest index, by selecting (5) five random plants, all the gathered information was then arranged properly before it underwent statistical analysis.

Statistical analysis

The collected data were analyzed using SAS (Statistical Analysis System) Software, which included performing ANOVA to calculate the impact of the G-E interaction Gomez and Gomez (1984) (Table 2). G-E interaction is potentially significant for key yield components. Data for each seeding environment were collected independently, and the Least Significant Test (LSD) was used to estimate the effects of genotypes, environment, and genotype × environment interaction.

Table 2: *ANOVA for 11 wheat genotypes across three planting environments (Dates).*

Dates (E)	(d-1) = 2	DMS	DMS/ GxDMS
Reps w/n E	D(r-1) = 6	…	…
Genotypes (G)	g-1 = 10	GMS	GMS/ GxDMS
G x E	(g-1) (d-1)= 20	GxDMS	GxDMS/EMS
Error	d(g-1) (r-1)= 60	EMS	
Total	dgr-1 = 98		

Where d = date of sowing, E = Environment, r = Number of replications, and g = Number of genotypes. Genetic variance $\sigma^2_g = (GMS - EMS)/r = X_1$*; Environmental variance =* $\sigma^2_e = EMS = X_2$*; Phenotypic variance =* $\sigma^2_p = X_1 + X_2 = X_3$*; Heritability =* $h^2_{bs} = \sigma^2_g/\sigma^2_p = X_1/X_3$*.*

Results and Discussion

Days to heading (Number)

Data obtained from all three environments showed a significant difference (P ≥ 0.01) in terms of heading intervals for the three planting dates (early 15th October, 15th November, and late 15th December). Mean values of heading intervals exhibited variation of wheat genotypes and significant GxE effects. The coefficient of variation was 0.20%, indicating a uniform performance throughout the trials (Table 3). In early planting, heading intervals were between 111.3 and 116.6, with a mean interval of 114.06, while normal plantings took a longer interval for heading, from 123.0 to 125.7 days, with a mean of 124.52 intervals. In late-sown genotypes, the heading intervals ranged from 110.3 to 112.3, with an average of 111.61. PR-149 produced minimum heading intervals for both early (111.3 intervals) and normal plantings (123.0), while Gulzar-19 exhibited the shortest heading interval of 110.0 days at late planting due to short duration. Across three plantings, the genotype PR-149 produced the shortest heading duration (114.89 intervals) (Table 5). In late planting, the vegetative cycle completes early, thus showing the increase of heading initiation for late planting compared to early and normal. Similarly, the previous results indicated that heading and maturity rates were significantly affected by sowing dates. The recommended sowing date (23 Nov.) recorded the highest value for each character in both growing seasons (Aglan *et al*., 2020). Early heading cultivars outperformed late heading cultivars because of the extended grain filling phase and completing a larger grain filling portion earlier when the temperature is cooler and more suitable (Tewolde *et al*., 2006).

Days to maturity

The significance was high (P ≥ 0.01) for maturity intervals, also substantial differences were observed among wheat cultivars and cultivar-date interactions, indicating that genotypes presented differences in performance across three environments. The coefficient of variance for the maturity interval was 0.15% across all three conditions (Table 3). Wheat genotype at early planting was 190.8 to 194.2,

Table 3: *Mean squares of wheat genotypes across early, normal, and late sown at CCRI, Pirsabak, Nowshera.*

Source	Df	Days to heading	Days to maturity	Plant height	Flag leaf area	Peduncle length	Tillers m^2	Spike length
Envir	2	3724.52**	6355.22**	2431.71**	777.64**	179.06**	13058.58**	34.77**
Reps. w/n	6	2.02	0.47	45.23	37.85	16.54	24.86	0.62
Geno	10	44594.55**	73270.45**	28803.78**	9299.24**	2110.23**	136269.07**	414.68**
Geno x Envir	20	44754.20**	77769.64**	29408.54**	9486.94**	2210.76**	168165.03**	670.97**
Error	60	1.80	1.22	31.00	6.78	7.38	76.95	2.42
CV (%)	-	0.20	0.15	1.16	0.85	2.04	1.38	1.38

, = significant at 5 and 1% probability level, respectively.*

Table 4: *Mean squares of wheat genotypes.*

Source	DF	Spikelets per spike	Spike weight	Grain weight	Grain per spike	Bundle yield	Grain yield	Harvest index
Envir	2	99.86**	2.67**	450.43**	859.67**	33838634.24**	3732305.06**	317.58**
Reps. w/n	6	2.05	0.02	6.98	16.83	984176.98	22316.8139	8.25
Geno	10	1176.36**	33.78**	5417.40**	10227.35**	342589125.76**	38094759.07**	3801.68**
Geno X Envir	20	1465.54**	81.49**	5483.00**	10575.94**	442691829.02**	48722562.37**	3969.47**
Error	60	1.46	0.04	9.88	26.27	335122.19	57091.18	8.63
CV (%)	-	1.27	1.24	1.33	1.78	1.98	2.54	1.52

**, ** = significant at 5 and 1% probability level, respectively.*

Table 5: *Mean performance of 11 wheat genotypes for days to heading, maturity, and plant height across three planting dates at CCRI Pirsabak Nowshera.*

Genotype	Days to heading (No)			Genotype mean	Days to maturity (No)			Genotype mean	Plant height (cm)			Genotype mean
	Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec	
PR-149	111.3	123.0	110.3	114.89	190.8	136.6	120.2	149.19	100.3	101.7	80.3	94.11
PR-152	115.9	126.7	113.0	118.52	190.4	140.8	121.2	150.81	99.0	102.7	79.0	93.56
PR-153	112.1	124.3	112.3	116.26	190.8	137.0	121.7	149.81	91.7	101.7	70.7	88.00
PR-154	112.3	123.0	110.7	115.33	192.0	138.0	119.8	149.93	96.0	104.3	77.3	92.56
PR-155	113.7	124.7	112.0	116.78	190.2	137.8	120.0	149.33	98.3	107.7	83.0	96.33
PR-156	111.6	123.0	113.3	115.96	189.2	137.4	118.8	148.48	95.0	102.0	77.7	91.56
PR-157	113.6	125.0	111.3	116.63	188.9	136.6	120.0	148.48	102.7	107.3	78.7	96.22
PR-158	115.7	124.3	111.7	117.22	192.1	138.4	120.8	150.44	99.3	108.3	76.7	94.78
Khaista-17	116.6	125.0	110.7	117.41	188.9	139.2	120.1	149.41	101.3	104.7	80.3	95.44
Gulzar-19	115.4	125.0	110.0	116.81	193.4	137.6	122.2	151.07	98.0	102.7	80.7	93.78
Pirsabak-19	116.6	125.7	112.3	118.19	194.2	137.0	116.3	149.19	99.3	105.3	81.3	95.33
Envir Mean	114.06	124.52	111.61	116.73	191.00	137.85	120.10	149.65	98.27	104.39	78.70	93.79
LSD0.05%	Environment			1.55				1.28				6.43
	Genotype			0.03				0.02				0.12
	Envir x Geno			2.19				1.80				9.09

with a mean of 191.00 intervals. With normal sowing, the intervals were 136.6 to 140.8, averaging 137.85 intervals. Delayed planting led to early wheat maturity compared to early and standard planting. Thus, the maturity intervals were seen earlier, ranging from 116.3 to 122.2 intervals, with a mean of 120.10 intervals. Genotype Khaista-17 showed shorter intervals to heading (188.9 intervals) under early planting conditions. In contrast, the genotype PR-157 showed the shortest (136.6) maturation intervals under normal planting conditions. And the genotype Pirsabak-19 showed the shortest (116.3) maturation intervals, under late planting conditions. On average across three plantings, genotype PR-156 required fewer intervals to reach maturity (148.48) intervals (Table 5). The maturity intervals were shorter when sown late compared to early and normal due to a short vegetative phase. On the other hand, a similar result was conducted by field experiment which was carried out at Etay El–Baroud Agricultural Research Station during the two successive seasons 2016/ 2017 and 2017/ 2018 to study the effect of four different sowing dates i.e. 1st, 15th, 30th November and 15th December, in heading and maturity case, the cultivar with sowing date at 15th December achieved lowest values of GDD in both studied seasons by (Yahya, 2020). Days to maturity showed positive genotypic correlation, indicating that a greater number of days to maturity will lead to more tillers per plant and will improve overall yield production (Anwar *et al*., 2009; Rauf *et al*., 2023).

Plant height (cm)

Plant height showed significant variance (P ≥

0.01) among the three planting dates in different environmental analyses. The CV was 1.16% across planting conditions. Also, plant height responded to changes in wheat genotypes as well as genotype by-environment interactions. Illustrating variations of genetic performances in three environments (Table 3). The plant heights of wheat genotypes varied from 91.7 to 102.7 cm for early planting, with an average of 98.27 cm. For normal conditions, heights ranged from 101.7 to 108.3 cm, averaging 104.39 cm, and for late planting, the plant height had a shorter vegetative phase; thus, plant heights were shorter, 70.7 cm and 83.0 cm, and the mean of 78.70 cm. In early planting, genotype PR-157 displayed the maximum plant height at 102.7 cm. In normal planting conditions, genotype PR-158 achieved the maximum plant height at 108.3 cm. PR-155 produced the maximum plant height at 83.0 cm, with late sowing. The maximum plant height was recorded for genotype PR-155 at 96.33 cm over three plantings (Table 5). With typical planting, there will be an expectation of higher values of plant height than with early and late planting. The plant height for GCA and SCA effects was non-significant, while ANOVA and other effects were highly significant (Hasnain *et al*., 2006). Mid-October and early-November sowing resulted in the tallest plants, while plant height was not affected by sowing dates (Khosravi *et al*., 2010).

Flag leaf area (cm^2)

The study showed statistically significant variation (P $\geq$ 0.01) and wheat genotypes and genotype-environment interactions, indicating that wheat genotypes showed varied performances across three planting dates. The percentage for the Coefficient of variance was 0.85% on all three dates (Table 3). The flag leaf area during early planting was 37.5 cm^2 to 58.2 cm^2, with a mean of 47.69 cm^2. In normal planting conditions, the flag leaf area varied from 51.6 cm^2 to 69.0 cm^2, averaging 58.77 cm^2. For late sowing, the flag leaf area was between 46.4 cm^2 and 64.7 cm^2, with an average of 53.16 cm^2. Genotype PR-155 exhibited the largest flag leaf area (58.2 cm^2), followed by PR-156 (55.4 cm^2) during early planting. Meanwhile, PR-149 exhibited the largest flag leaf area (69.0 cm^2), whereas genotype PR-155 had a flag leaf size of 64.4 cm^2 under normal conditions. Similarly, the PR-154 had the highest flag leaf area (64.7 cm^2). Across three plantings, the largest primary flag leaf area was observed in genotype PR-155 (57.43 cm^2) (Table 6). Hence, wheat genotypes treated with normal planting conditions showed a greater flag leaf area compared to those planted at early or late timings under late planting conditions. Three replications with the RCBD method were conducted in two consecutive growth seasons of bread wheat. As a result of two years of investigation, wheat plants with an excessively delayed sowing date showed a significant reduction in flag leaf angle, flag leaf area, main stem spike length, and photosynthesis rate (Zheng *et al*., 2021). Wheat yield is affected by flag leaf angle, flag leaf area, and flag leaf duration traits (Simon, 1999). Another result also indicates that prolonged duration of green leaf area after heading could lead to improvement in yield potential and grain volume (Blake *et al*., 2007).

Peduncle length (cm)

Peduncle length exhibited significant differences (P $\geq$ 0.01) among the three planting dates. Peduncle length was affected by variations in wheat genotypes and GxE interactions. Displaying differences in genetic performance across three environmental conditions. The coefficient of variation percentage for peduncle length was 2.04% (Table 3). During early planting, peduncle lengths ranged from 24.1 cm to 33.7 cm, with an average length of 30.34 cm. Similarly, the genotype performance for peduncle length ranged from 19.6 to 28.5 cm, with an average of 25.78 cm in a normal environment. The late-sown genotypes produce a length of 13.7 cm to 25.9 cm, with a mean of 19.73 cm. Genotype Khaista-17 had the shortest length of 24.1 cm under early planting conditions. The genotype Khaista-17 produced peduncle lengths of 19.6 cm under normal planting conditions. Additionally, the genotype Khaista-17 produced a peduncle length of 13.7 cm under late planting conditions. In three plantings, genotype Khaista-17 showed the shortest peduncle length at 19.15 cm (Table 6). Paul and Duhan (2021) also concluded in their experiment that Peduncle length, particularly the upper exposed part, varies significantly under heat stress conditions across different sowing dates. Late sowing dates (December 24, January 24, and February 24) resulted in shorter peduncle lengths compared to timely sowing (November 24) due to increased heat stress. Late sowing exposes wheat plants to high temperatures, resulting in a reduction in peduncle length (Bonari *et al*., 2020).

Table 6: *Mean performance of 11 wheat genotypes for flag leaf area cm², peduncle length, and tillers m² 11 genotypes across three planting dates at CCRI Pirsabak Nowshera.*

Genotype	Flag leaf area (cm²)			Genotype mean	Peduncle length (cm)			Genotype mean	Tillers m² (cm)			Genotype mean
	Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec	
PR-149	49.8	69.0	53.3	57.36	29.1	27.7	18.6	25.14	256.7	292.7	78.0	209.11
PR-152	41.3	54.1	52.4	49.30	29.2	25.3	22.8	25.75	243.3	254.7	108.0	202.00
PR-153	41.4	53.2	50.5	48.36	28.8	25.7	15.3	23.27	256.0	285.3	130.0	223.78
PR-154	50.5	54.6	64.7	56.59	32.6	28.5	22.0	27.71	246.0	252.0	111.7	203.22
PR-155	58.2	64.4	49.7	57.43	32.0	26.4	25.9	28.09	250.0	276.0	76.0	200.67
PR-156	55.4	56.3	53.5	55.05	28.7	23.6	16.6	22.98	256.0	266.0	94.0	205.33
PR-157	51.7	63.2	46.4	53.77	33.7	26.4	24.7	28.28	240.0	274.0	76.0	196.67
PR-158	47.5	51.6	49.5	49.54	30.7	23.9	19.3	24.64	234.0	288.0	78.0	200.00
Khaista-17	37.5	58.3	56.8	50.86	24.1	19.6	13.7	19.15	246.0	287.3	86.0	206.44
Gulzar-19	48.4	61.9	53.3	54.54	32.5	27.4	19.7	26.53	228.0	279.3	94.0	200.44
Pirsabak-19	42.9	59.9	54.6	52.45	32.2	28.1	18.4	26.24	246.0	248.7	96.0	196.89
Envir Mean	47.69	58.77	53.16	53.21	30.34	25.68	19.73	25.25	245.64	273.09	93.42	204.05
LSD0.05%	Environment			3.01				3.14				10.13
	Genotype			0.06				0.06				0.19
	Envir x Geno			4.25				4.44				14.33

Tillers per m²

The environmental differences for tillers per m² were significant ($P \geq 0.01$). The differences of wheat cultivars and cultivar-date were significant too; tillers per m² were affected by variations in wheat genotypes and GxE interactions, displaying differences in genetic performance across three environmental conditions, which means that there was a difference in the genotypic performance of wheat under three different conditions. The CV for the tillers per m² was 1.38% (Table 3). The total number of tillers per m² of wheat genotypes varied from 228.0 to 256.7 under early planting, with a mean of 245.64. In normal planting, it ranged from 248.7 to 292.7, averaging 273.09, while in late sowing, it ranged from 76.0 to 130.0, with an average of 93.42. Hence, wheat genotypes subjected to normal planting exhibited a greater number of tillers per m² compared to those planted early or late. In early planting, genotype PR-149 exhibited the highest number of tillers m² (256.7). Meanwhile, PR-149 exhibited the highest number of tillers per m² (292.7) under normal sowing conditions. In late planting, PR-153 recorded the maximum tillers per m² (130.0). Across three plantings, genotype PR-153 (223.22) had the highest tillers. A net decline occurs due to early and delayed planting, with a decrease of 27.45 between normal and early planting, and a substantial reduction of 179.67 between normal and late sown wheat plants (Table 6). Previously, based on two two-year studies it is evident that the sowing of wheat on 5th November was found to be more suitable than the rest of the sowing dates, as it recorded a significantly higher number of effective tillers (399.91 and 411.94 m⁻²) compared to the rest of the sowing dates, except 25th October during both years (Bhayal *et al*., 2022). Sowing in mid-November resulted in the highest number of tillers/m² (Chaulagain *et al*., 2024).

Spike length (cm)

The spike length displayed significant differences ($P \geq 0.01$) across three different conditions. The coefficient of variation % was 1.38%. The duration of spikes showed considerable variability among wheat genotypes and their interactions with the environment (Table 3). Spike lengths of Early planting varied from 9.8 cm to 12.9 cm, averaging 11.47 cm, whereas normal environment spike lengths ranged from 11.7 cm to 14.1 cm, with a mean of 12.67 cm, and late planting spike lengths spanned from 8.9 cm to 10.5 cm, averaging 9.50 cm. In early planting, genotype Khaista-17 had the maximum spike length at 12.9 cm, whereas genotype PR-155 had the longest spike length (14.1 cm), under normal planting conditions. In the late sowing, the genotype PR-155 showed the highest spike length (10.5 cm). The genotype PR-155 showed the longest spike

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length at 12.38 cm over three plantings. Showing 1.2 cm contraction from the normal planting to early planting and 3.17 cm from normal planting to late planting period due to the period involved (Table 7). A study in Egypt found that the spike length was significantly higher for wheat sown on 30th November compared to later dates (Fadle *et al.*, 2016). Similarly, in Bangladesh, the spike length was highest for wheat sown on 18th November and decreased with later sowing dates (Mahmud *et al.*, 2016).

Spikelets per spike

The study of genotypes revealed significant variations (P $\geq$ 0.01) in spikelets per spike among the three different dates. Wheat genotypes and genotype-environment interactions showed significant variation. The percentage of the coefficient of variation among various wheat genotypes was 1.27% (Table 4). The spikelets per spike for early planting ranged from 16.8 to 21.3, averaging 19.32. In a normal condition, the spikelets per spikes were 20.5 to 23.2, with an average of 22.11. Late planting spikelets per spike were 12.7 to 17.2, averaging 15.32. Wheat genotypes had the greatest number of spikelets per spike under normal planting conditions compared to the other two sowings. In early planting, genotype PR-158 developed the highest number of spikelets per spike (21.3). On the other hand, genotype PR-154 had the highest number of spikelets per spike (23.2) under typical planting conditions. Under late sowing conditions, the genotype PR-149 showed the highest number of spikelets per spike with 17.2. Across three plantings, genotype PR-149 showed the highest average number of spikelets per spikes at 19.79, a drop of 2.79 spikelets per spike was observed between early and normal planting, while a reduction of 6.79 spikelets per spike was noted between normal and late planting due to delayed sowing (Table 7). Hence, the normal planting performed better than the other two sowing dates. The number of spikelets per spike generally decreases with delayed sowing, but some varieties show stable performance under late sowing conditions (Basheir *et al.*, 2023). Sowing on November 10th or 15th is often superior in terms of grain yield and spikelet number compared to both earlier and later sowing dates (Wahid and Al-Hilfy, 2018). Another research also found that high temperature and an increase in the day length can potentially reduce the initiation of spikelets per spike (Arduini *et al.*, 2009).

Spike weight (g)

Spike weight showed substantial significance (P $\geq$ 0.01) as well as differences among wheat genotypes and genotype-environment interactions among three planting dates. The percentage coefficient of variation for various wheat genotypes was 1.24% (Table 4).

Table 7: *Mean performance of 11 wheat genotypes for spike length, spikelets per spike, and spike weight across three planting dates at CCRI Pirsabak Nowshera.*

Genotype	Spike length (cm) Early 15th Oct	Normal 15th Nov	Late 15th Dec	Genotype mean	Spikelets per spike (no) Early 15th Oct	Normal 15th Nov	Late 15th Dec	Genotype mean	Spike weight (g) Mean 15th Oct	Normal 15th Nov	Late 15th Dec	Genotype mean
PR-149	12.2	13.6	10.2	12.00	19.5	22.6	17.2	19.79	3.2	3.2	3.1	3.16
PR-152	11.6	12.7	9.6	11.28	20.5	22.2	15.4	19.36	3.2	3.3	3.2	3.27
PR-153	11.7	12.5	8.9	11.04	20.1	23.1	16.0	19.76	3.0	3.2	2.3	2.82
PR-154	11.6	12.7	9.5	11.24	19.5	23.2	15.6	19.42	3.4	3.2	2.5	3.01
PR-155	12.5	14.1	10.5	12.38	18.5	21.8	13.7	18.01	3.5	3.4	2.6	3.15
PR-156	10.7	12.7	9.5	10.97	16.8	21.4	15.1	17.77	3.6	3.1	2.1	2.94
PR-157	10.8	11.8	9.2	10.60	19.9	22.9	14.7	19.13	3.3	3.7	2.4	3.14
PR-158	11.2	13.4	9.0	11.22	21.3	21.2	16.3	19.60	3.2	3.2	2.6	3.02
Khaista-17	12.9	11.9	10.0	11.59	17.1	22.2	12.7	17.33	3.6	3.7	3.3	3.52
Gulzar-19	9.8	11.7	9.1	10.21	19.7	20.5	16.3	18.86	3.0	3.7	2.6	3.11
Pirsabak-19	11.3	12.2	9.0	10.83	19.5	22.2	15.5	19.05	3.6	3.0	2.6	3.10
Envir Mean	11.47	12.67	9.50	11.21	19.32	22.11	15.32	18.92	3.33	3.33	2.68	3.11
LSD0.05%	Environment			0.91				0.03				0.24
	Genotype			0.02				1.97				0.00
	Envir x Geno			1.29				195.82				0.33

Table 8: *Mean performance of 11 wheat genotypes for grain weight, grain per spike, and bundle yield across three planting dates at CCRI Pirsabak Nowshera.*

Genotype	Grain weight (g)			Genotype mean	Grain per spike (no)			Genotype mean	Bundle yield (kg/ha)			Genotype mean
	Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec	
PR-149	37.2	40.4	38.6	38.74	65.3	70.4	55.4	63.70	10859.7	13835.3	4260.0	9651.67
PR-152	38.0	39.5	40.1	39.23	75.4	54.0	50.1	59.87	12035.7	15471.1	4260.0	10588.93
PR-153	37.5	41.2	37.0	38.57	54.3	66.7	38.8	53.25	10719.6	15217.8	3641.7	9859.67
PR-154	42.1	36.0	41.3	39.79	55.4	57.7	45.0	52.71	12042.3	14717.8	4546.7	10435.59
PR-155	42.0	38.6	39.9	40.18	65.6	64.2	49.1	59.63	11809.3	15253.0	3007.0	10023.11
PR-156	41.3	40.0	39.6	40.30	62.3	57.1	45.2	54.85	8767.3	16132.7	5097.7	9999.22
PR-157	42.2	39.7	34.1	38.66	57.0	64.1	44.6	55.25	9619.7	13512.7	5098.0	9410.11
PR-158	46.7	42.6	42.8	44.04	50.3	61.1	43.1	51.49	11537.8	15236.0	3335.6	10036.44
Khaista-17	43.0	41.1	40.9	41.65	64.8	62.8	48.0	58.53	13740.0	16526.7	4802.0	11689.56
Gulzar-19	42.8	39.1	43.1	41.69	50.2	63.5	47.4	53.70	12513.3	14567.3	5313.0	10797.89
Pirsabak-19	45.4	46.3	40.6	44.11	54.1	51.8	45.2	50.36	10596.0	14819.7	4416.0	9943.89
Envir Mean	41.66	40.43	39.81	40.63	59.53	61.22	46.53	55.76	11294.61	15026.36	4343.41	10221.46
LSD0.05%	Environment			3.63				5.92				668.55
	Genotype			0.07				0.11				12.41
	Envir x Geno			5.13				8.37				945.48

Wheat genotypes had spike weights ranging from 3.0 to 3.6 g under early planting, averaging over 3.3 g, and it was 3.0 to 3.7 g for normal conditions, averaging over 3.3 g, and similarly it was 2.1 to 3.3 g under late planting, averaging over 2.6 g, Genotype PR-156, Khaista-17 and Pirsabak-19 each produces the highest spike weight of 3.6 g, under early planting conditions. On the other hand, genotypes PR-157, Khaista-17, and Gulzar-19 showed the highest spike weight (3.7 g) under normal planting conditions. During late sowing, Khaista-17 exhibited the highest spike weight of 3.3 g under late sowing conditions. Throughout three plantings, the highest spike weight was observed in genotype Khaista-17 (3.52 g) (Table 7). Hence, it is known that spike weight increases under early and normal planting conditions, whereas there will be a reduction if it is sown under late planting conditions. In the previous field experiment, which was conducted in India (UP), Chandra Shekhar Azad University of Agriculture and Technology. The experimental treatment was the date of sowing as a main factor in the different dates of sowing; the 15th of November sowing of crops resulted in significantly higher spike weight (Kumari *et al*., 2022). Sowing dates affected the spike weight as spike to stem ratio varied in response to photoperiod (Bassu *et al*., 2010).

Thousand grain weight (g)

There were major differences (P > 0.01) across the different climates in thousand-grain weight at each planting date. Wheat genotypes and G×E interactions also showed significant variations. The coefficient of variation for the different wheat genotypes was 1.33% (Table 4). Wheat genotypes had thousand-grain weights ranging from 37.2 g to 46.7 g under early planting, averaging 41.66 g, and it was 36.0 g to 46.3 g under normal conditions, averaging 40.43 g, and from 34.1 g to 43.1 g under late planting, averaging 39.81 g. Genotype PR-158 exhibited the highest thousand-grain weight of 46.7 g under early planting conditions. On the other hand, genotype Pirsabak-19 showed the highest thousand-grain weight (46.3 g), under normal planting conditions during late sowing. Gulzar-19 exhibited the highest thousand-grain weight at 43.1 g, under late sowing conditions. Throughout three plantings, the highest thousand-grain weight was observed in genotype Pirsabak-19 (44.11 g), with a decrease of 0.6 g from early to normal planting and 1.5 g from normal to late planting, resulting from late planting (Table 8). Therefore, the predicted thousand-grain weight was expected to be higher under normal planting conditions compared to early and late planting. Gyawali *et al*. (2023) also found in their experiment that thousand-grain weight was maximum when the wheat was sown on 12th of November and was reduced with the subsequent delay in sowing. Another study also concluded that early sowing leads to a higher thousand-grain weight while late sowing results in lower thousand-grain weight (Wajid *et al*., 2004).

Grain per spike

The wheat genotypes and their interactions with the environment were highly significant (P ≥ 0.01) among the three sowing dates. The global coefficient of variation between the several genotypes of wheat when tested under three sowing dates was 1.78% (Table 4). The grains/spikes were 50.2 to 75.4 at early planting. With an average of 59.53, whereas in normal conditions, it was 51.8 to 70.4, averaging 61.22, and under late planting, values varied from 38.8 to 55.4, with an average of 46.53. In early planting, genotype PR-152 demonstrated the highest grains per spike count (75.4). Conversely, genotype PR-149 had the highest grains per spike at 70.4, under standard planting conditions. Under late sowing conditions, the genotype PR-149 had the highest grains/spike at 55.4. Throughout three plantings, the greatest grain/spike was seen in genotype PR-149 (63.70). The decline in grain/spike was 1.69, between early and normal planting, and in late sowing, the decrease in yield was 14.69 due to late sowing (Table 8). The result showed that the grain/spike was higher under the normal planting density as compared to early planting and late planting densities. According to another study, the 5th of November sown crops recorded significantly higher grains per spike compared to the rest of the sowing dates (Yusuf *et al*., 2019). Early and mid-November sowing resulted in higher grain/spike as compared to late sowing (Praveen *et al*., 2018).

Bundle yield (Kg/ha)

The overall data for bundle yield throughout sowing dates showed important variances (P ≥ 0.01). The bundle yield exhibited significant variations among wheat genotypes and GxE interactions; also, the Coefficient of variation was 1.98% for multiple genotypes (Table 4). Bundle yield with early sowing varied from 8767.3 Kg/ha to 13740.0 Kg/ha, with a mean of 11294.61 Kg /ha. Yields of normal sowing varied from 13512.7 Kg/ha to 16526.7 Kg/ha, with an average of 15026.36 Kg/ha. Late planting yields ranged from 3007.0 Kg/ha to 5313.0 Kg/ha, averaging 4343.41 Kg/ha. In early planting, Khaista-17 demonstrated the highest bundle output at 13740.0 Kg/ha. In standard planting conditions, genotype Khaista-17 demonstrated the highest bundle yield at 16526.7 Kg/ha. Whereas Gulzar-19 yielded the highest bundle weight (5313.0 Kg/ha) in late sowing. The bundle yield was best for genotype Khaista-17 (11689.56 Kg/ha) when averaged across three planting dates. The reduction was 3731.75 Kg per hectare between early and normal sowing, whereas a massive drop of 10682.95 Kg/ha was seen at late sowing compared to normal sowing (Table 8). Hence, the increase in bundle production was greater with normal planting compared to early planting and late planting. Roshan *et al*. (2021) also found out that the early sown wheat has the better and maximum biological/bundle yield compared to that sown late. Wheat sown early in November produced a higher bundle yield due to exposure to an optimum growth duration (Tahir *et al*., 2019).

Grain yield (Kg/ha)

The environmental differences were significant (P ≥ 0.01) among the three sowing timings. Grain production exhibited significant variability among wheat genotypes and their interactions with the environment, and the performance of each genotype across three different situations. The coefficient of variation for several wheat genotypes over three sowing dates was 2.54% (Table 4). the grain yields of wheat genotypes varied from 3469.0 Kg/ha to 4917.7 Kg/ha for early planting, with an average of 4333.00 Kg/ha: from 3828.7 Kg/ha to 5042.2 Kg/ha under normal conditions, with an average of 4512.57 Kg/ha, and from 1073.3 Kg/ha to 1782.2 Kg/ha for late sowing, with an average of 1384.65 Kg/ha. Normal planting produced the highest grain production for wheat genotypes, compared to early and late planting. In early planting, genotype Gulzar-19 had the best grain yield at 4917.7 Kg/ha. Under standard planting conditions, genotype Pirsabak-19 yielded the most grain at 5042.2 Kg/ha. PR-156 exhibited the maximum grain yield of 1782.2 Kg/ha in late sowing. The maximum grain production was recorded for genotype PR-155 (3656.11 Kg/ha) throughout three plantings; the reduction was 124.5 Kg/ha from early to normal planting and 3260.0 Kg/ha from normal to late planting (Table 9). The rise was greater in grain yield for normal planting compared to early or late planting. In the middle-lower Yangtze River Basin, China, grain yield decreased by approximately 0.97% for each day of deviation from the optimal sowing date, highlighting the importance of timely sowing (Liu *et al*., 2021). In Egypt, sowing on November 5th produced the highest grain yield and quality for certain genotypes, while December 5th was optimal for others. Sowing on January 5th resulted in the lowest yield (Shalaby *et al*., 2023).

Table 9: *Mean performance of 11 wheat genotypes for grain yield and harvest index across three planting dates at CCRI Pirsabak, Nowshera.*

Genotype	Grain yield (kg/ha)			Genotype mean	Harvest index (HI)			Genotype mean
	Early 15th Oct	Normal 15th Nov	Late 15th Dec		Early 15th Oct	Normal 15th Nov	Late 15th Dec	
PR-149	3469.0	4691.3	1275.6	3145.30	31.9	34.0	29.9	31.92
PR-152	4429.1	4200.1	1073.3	3234.19	36.9	27.4	25.2	29.84
PR-153	3959.7	4528.9	1391.0	3293.19	36.9	30.1	38.4	35.14
PR-154	3956.1	4567.1	1662.3	3395.19	32.9	31.1	36.6	33.54
PR-155	4892.7	4602.3	1473.3	3656.11	41.7	30.2	49.0	40.30
PR-156	4617.8	4563.9	1782.2	3654.63	52.9	28.3	35.0	38.72
PR-157	4333.3	5022.3	1142.0	3499.22	45.0	37.2	22.4	34.87
PR-158	4681.1	3828.7	1104.3	3204.70	40.6	25.1	33.1	32.93
Khaista-17	4495.7	4413.3	1389.1	3432.70	32.8	26.7	28.8	29.44
Gulzar-19	4917.7	4178.0	1622.0	3572.56	39.4	28.7	30.5	32.87
Pirsabak-19	3910.9	5042.2	1315.8	3422.96	36.9	34.0	29.9	33.63
Envir Mean	4333.00	4512.57	1384.64	3410.07	38.91	30.25	32.62	33.93
LSD0.05%	Environment			275.94				3.39
	Genotype			5.12				0.06
	Envir x Geno			390.24				4.80

Harvest index

The harvest index (HI) had a coefficient of variation (CV) of 1.52% under three given environments. The HI also showed significant differences ($P \geq 0.01$), as well as the interaction between genotype and environment for wheat genotypes was also extremely significant ($P \geq 0.01$) for the harvest index, indicating that genotypes exhibited varying performance across the given three environments (Table 4). Under early-sown wheat genotypes, the harvest index ranged from 31.9 to 52.9, averaging over 38.91. Harvest index was 25.1 to 37.2 in a normal environment, with an average of 30.25. And for late sown genotypes it was 22.4 to 49.0 with an average of 32.62. Genotypes PR-156 (52.9) had the highest harvest index in early planting; similarly, in normal planting, PR-157 (37.2) had the highest harvest index. Furthermore, genotype PR-155 (49.0) had the highest harvest index for late sowing. Averaged over three plantings, genotype PR-155 (40.30) have harvest index had the highest harvest index (Table 9). The result showed that the harvest index for early and late was better than normal sown wheat. A field experiment conducted by Ravichandran *et al.* (2021) concluded that out of three sowing dates, mid-November-sown varieties recorded the highest harvest index. Another field experiment also concluded that 25th November sown varieties produced the highest harvest index as compared to 15th December sowing (Kamrozzaman *et al*., 2016).

Conclusion

This study concluded that the most suitable time for sowing is 15th November, because it outperformed every other sowing date. Sowing in early October was also better for most of the yield-related traits, but the late sowing in December is not recommended for our tested genotypes, as compared to the other two dates. Genotypes PR-149, PR-155, and cultivar Khaista-17 produced the best grain yield across the three different sowing dates. From this research, it is suggested that Genotype PR-155, which outperformed every other genotype across different agro-morphological traits, can be used in the future.

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Novelty Statement

The 15th of November planting showed prominent production, while the 15th of December sowing produced the minimum yield. The genotype PR-149 produced the highest number of tillers/m^2 (292.7), while October-sown genotypes produced the highest number of grains per spike for line PR-152 (75.4) and thousand-grain weight (46.7 g) for line PR-158.

Author's Contribution

Muhammad Asif: Research Experiment Executed/ MS drafting.
Khilwat Afridi:Field Trial Supervision.
Aysha: Data collection.
Mudassar Iqbal, Farooq Jan and Ikramullah Khan: Proofreading.
Kashmala Jabbar and Haleema Bibi: Data analysis.
Abdur Rauf: Research Supervision/MS drafting and proofreading.

Generative AI and AI-assisted technology statement
Generation AI and AI-assisted Technology Statement: It is certified that AI-assisted technology has not been used for the generation of this project data.

Conflict of interest
The authors have declared no conflict of interest.

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