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Optimizing Sowing Window for Local and Chinese Elite Lines under Changing Climate

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Abstract: Climate change threatens major global crops including wheat of subtropical regions, especially during critical developmental stages. To address this concern, researchers try to identify exotic genetic diversity with pronounced stress tolerance or avoidance or find improved genotypes with optimal sowing time. Current research evaluated seven exotic Chinese wheat genotypes (MY4094, MY1617, MY1416, MY2914, MY1501, MY1419, and MY902) for yield and associated characters along with a local check variety (PS-15) under optimal (1st November), moderate (16th November), and late sowing times (1st December) during both years. The result revealed that delayed sowing reduced yield and yield components of the tested genotypes, including the local check. Genotype MY1617 performed best under optimal sowing in terms of grain yield and yield attributes, with a 5% increase over the local check. MY902 had the highest seed yield among late-sown genotypes. Correlation analysis showed that grain yield was positively correlated with grains per spike, days to anthesis, booting, and heading. The current study provides important information for wheat breeders to exploit exotic genetic materials under a diverse sowing window and develop genotypes with improved traits that may boost wheat growers' production.

Keywords: wheat lines; sowing dates; growth; biomass production; grain yield

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Citation: Khan, B.; Arif, M.; Munsif, F.; Anjum, M.M.; Wójcik-Gront, E.; Khan, A.; Ahmad, I.; Ren, Y.; Zhao, C.; Liao, X.; et al. Optimizing Sowing Window for Local and Chinese Elite Lines under Changing Climate. *Agronomy* **2022**, *12*, 2232. https://doi.org/10.3390/agronomy12092232

Academic Editor: Rohit Mago

Received: 24 July 2022
Accepted: 23 August 2022
Published: 19 September 2022

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1. Introduction

One of the most serious consequences of climate change is the potential increase in food insecurity [1]. The predicted impact of climate change on crop production and productivity can be mitigated through crop management adaptations such as shifted planting dates [2,3]. Considerable research has been carried out in an effort to identify genotypes that are capable of producing high yields while maintaining consistent performance [4]. On the other hand, the majority of highly stable genotypes are less predictable when shifted sowing dates are considered. Climate change's impact on identifying high-yielding genotypes and adjusting sowing dates across temporal and regional scales has been a focus of research [5].

Wheat (*Triticum aestivum* L.) is a major rabi season crop that is grown on both irrigated and rain-fed areas and is well adapted to temperate regions. China, India, United States of America, Russian Federation, and Canada are major wheat producers worldwide. Among them, China is the largest producer of wheat and is responsible for 16.9% of global wheat

production, followed by India. These major producer countries contribute more than half of global wheat production [6]. Worldwide, Pakistan's rank is 8th in the leading wheat-producing countries [7] and wheat covers the maximum cropped area as compared to other crops. Wheat yield in Pakistan has been low and static for the past several decades due to various physiological, agronomic, and genetic factors. Among agronomic factors, planting time is one of the most important factors that limits wheat yield by affecting the time and duration of the vegetative and reproductive stage of crops [6,8].

Choosing an appropriate time is the key factor in achieving high yield due to the variability in environmental changes [8]. Optimizing planting time and the suitable genotype may enhance crop growth, leading to higher yield and associated traits [9,10]. Too early or late sowing affects germination, growth, grain development, leads to frequent death of embryos, and produces poor plants with weak root systems due to cold or heat injury, which leads to a reduction in yield [11]. In contrast, the optimum planting time produces the maximum yield due to longer duration of grain development and tillering, which produces the maximum number of tillers, number of spikes, grains spike^{-1}, and thousand grain weight [12,13]. Ali et al. [14] reported that wheat crop sown on 15th and 31th December caused a reduction in yield by 27% and 52%, respectively, as compared to sowing on 1st November. Generally, a delay in sowing a day from the optimum time decreased grain yield by 1 percent, which also increased the risk of crop failure by disease and pest attack [15]. Grain yield of wheat can be increased by 10 to 30% through the management of planting time, environmental conditions, and cultivars [16]. The scope of planting time is not only bound to the environment but also has an impact on insect, pest, and disease attacks. Due to climate change, the pattern of rainfall and temperature has been changed, so the optimum planting time of wheat has been postponed from late October to mid-November in the recent past in Pakistan and is expected to shift to early December [17].

Another important factor which is limiting wheat productivity in Pakistan is unavailability of high-yielding and disease-resistant varieties [10]. The yield potential and average yield of our local varieties in Pakistan are very low compared with other leading wheat-producing countries. To meet the high demand for grains for the rapidly growing population of Pakistan, it is the need of the day to identify such high-yielding wheat varieties which can highly contribute yield per unit area and are adapted to our local environment. Grain yield is a complex trait which often relies on genotypic traits, yield components, and different environmental conditions [18,19]. Because yield has a polygenic character and thus can be enhanced by changing genetic characters and environment, the idea to increase yield components and varieties is of great importance for improving actual yield [20]. Grain yield, biological yield, and other yield components have a direct relationship with improved varieties [21,22]. Concerning yield potential, the modern wheat genotypes have huge variation, which reveals that improved crop management can enhance grain yield [23].

In the past, plant breeders and agronomists have developed many high-yielding wheat genotypes for general cultivation but their performance is not as good as expected. There can be many reasons for this failure, but the well-known reasons are that either these varieties have lost their potential adaptability to the changing climate or they have susceptibility to various fungal diseases such as smut and rust [24,25]. Self-sufficiency in wheat can be obtained more specifically by growing the most appropriate varieties according to the climatic condition. Consequently, wheat varieties need continuous evaluation with a wide range of adaptability or sensitivity to achieve the desirable traits to enhance wheat production in Pakistan [26].

Keeping in view the above-mentioned factors, this study was carried out to compare the Chinese wheat genotypes with an elite local variety for yield and yield traits and to determine the optimum planting time for wheat lines under the agro-ecological conditions of northern Pakistan.

2. Materials and Methods

2.1. Experimental Site Characteristics

Two field experiments were conducted at Agronomy Research Farm, The University of Agriculture, Peshawar, Pakistan during the winter season 2019–2020 and 2020–2021. The experimental site is located at latitude (34.01° north), longitude (71.35° east) with an elevation of 331 m above the mean sea level. It exhibits a subtropical climate with an average annual rainfall of 360 mm. The summer months, i.e., May–September, have an average higher temperature and lower temperature of 40 °C and 25 °C, respectively, whereas winter months, i.e., December–March, have an average minimal temperature of 4 °C and an average maximal temperature of 18.4 °C [27]. The research farm is irrigated by the Warsak River Canal originating from the Kabul River. The soil of the experimental site is slightly alkaline in reaction and silt clay loam in texture, with most of the nutrients deficient in soil (Table 1).

Table 1. Physicochemical properties of soil at the experimental site.

Property	Values
pH	8.23
EC (dS m^{-1})	0.16
Sand (%)	8.67
Silt (%)	52.43
Clay (%)	38.90
Textural class	Silty clay loam
Bulk Density (mg^{-3})	1.35
CEC ($cmol_c$ kg^{-1})	30.1
Total organic C (g kg^{-1})	12.7
Total N (g kg^{-1})	0.61
Total P (g kg^{-1})	0.24
Total K (g kg^{-1})	14.3
Available P (mg kg^{-1})	3.20
Available N (mg kg^{-1})	23.7
Available K (mg kg^{-1})	85.8

2.2. Physicochemical Properties Analysis of Soil

Composite samples were collected from soil depth of 0–15 cm for examination of physicochemical properties prior to sowing of the crop. The samples were air-dried and finely crushed and analyzed for texture, pH, EC, OC, N, P, and K as well as soil bulk density. The categorization of soil for pH and EC was performed based on the outline of New Mexico State University (NMSU) [28] and the Foth [29] method was used for identification of textural classes. Total nitrogen content (%) in soil was assessed by Kjedhal's apparatus [30], whereas available phosphorus content (mg kg^{-1}) was determined by the Olsen extractant sodium bicarbonate method [31]. The exchangeable potassium was determined by the AB-DTPA extract method [32]. The soil organic carbon was determined by Walkley and Black [33] using the wet oxidation method.

2.3. Treatments and Field Research

The experiment was performed in a randomized complete block design with a split plot arrangement with three replications. The experimental plot was 3 m × 4.5 m with row space of 30 cm accommodating 15 rows. The field was ploughed down using a cultivator (which can plough to a depth of 10–15 cm), followed by a rotavator (which can plough to a depth of 20 cm). Treatments consisted of sowing dates (1st November, 16th November, and 1st December) and wheat genotypes (MY409-4, MY1617, MY1416, MY291-4, MY1501, MY1419, and MY902) with one local wheat check (PS-15). The main plots were allotted to sowing dates whereas the subplots were assigned to wheat lines. The crop was sown manually in rows through a hand hoe with the seed rate of 120 kg ha^{-1}.

Nitrogen and phosphorous were applied from a urea and DAP source at the rate of 120 and 90 kg ha^{-1}, respectively. Nitrogen was applied in three splits, i.e., 15% applied during seedbed preparation, 42.5% with first irrigation, and 42.5% at the tillering stage. All the phosphorous was applied at the time of seedbed preparation. Irrigation water was applied at proper growth stages considering the requirement of the crop and weather condition. Weeds were controlled by applying the broad and narrow leaf herbicide Sulfonet 4% OD (Florasulam 1% w/v 0.98% $w/w \pm 0.02$, Mesosulfuron Methyl 3% w/v 2.94% $w/w \pm 0.02$) at the rate of 150 milliliter $acre^{-1}$ to keep the weed population below the threshold level. Roguing was performed for the removal of off-types of plants from the field. The crop was reaped at harvest maturity when spike color turned to brownish. The crop was kept in the field for sun-drying and then threshed with a mini-thresher.

2.4. Plant Parameters and Analysis

2.4.1. Phenological Attributes

Data on phenological traits were noted by computing the days taken from the planting date to when 75% of plants reached each phenological developmental stage, i.e., jointing, booting, heading, anthesis, and physiological maturity in each experimental plot, while days to emergence were noted by counting the number of days taken from the planting date until 75% of seedlings came out from the soil surface in each plot.

2.4.2. Growth Attributes

Emergence (m^{-2})

Data regarding emergence (m^{-2}) were recorded for three randomly selected rows in each plot in a one-meter length row through the meter rod and were then converted to emergence (m^{-2}) according to the given formula:

$$\text{Emergence}\left(m^{-2}\right) = \frac{Seedling\ counted\ in\ three\ central\ rows}{row - row\ distance \times row\ length \times no.\ of\ rows} \quad (1)$$

Tillers (m^{-2})

Three rows were randomly selected for recording data on tillers (m^{-2}) from each plot, having one-meter length through the meter rod, and were then changed to tillers (m^{-2}) through the below formula:

$$\text{Tillers}\left(m^{-2}\right) = \frac{Tillers\ counted\ in\ three\ central\ rows}{row - row\ distance \times row\ length \times no.\ of\ rows} \quad (2)$$

Flag Leaf Area (cm^2)

Flag leaf area was measured by randomly selecting five flag leaves from each experimental unit at the post-anthesis stage, and their length and breadth were measured using measuring tape, and then leaf area was measured through the below formula [28]:

$$\text{Flag leaf area}\left(cm^2\right) = Leaf\ length \times Leaf\ width \times 0.75 \quad (3)$$

Plant Height (cm)

The height of the plants was measured from the base of the stem to the tip of the spike without awns for five randomly selected plants in every experimental plot at physiological maturity and was then averaged.

Spike Length (cm)

The length of spikes excluding awns was measured from the base of the first spikelet to the tip of the last spikelet for five randomly selected spikes at physiological maturity from each plot by using the measuring scale and was then averaged.

2.4.3. Yield and Yield-Related Attributes

Number of Spikes (m^{-2})

Data relating to spikes (m^{-2}) were noted by three randomly selected rows from each plot with one-meter length through the meter rod; all spikes in the meter rod were counted and then changed into spikes (m^{-2}) by the given formula:

$$\text{Spikes}\left(m^{-2}\right) = \frac{Spikes\ counted\ in\ three\ central\ rows}{row - row\ diistance \times row\ length \times no.\ of\ rows} \quad (4)$$

Spikelets $Spike^{-1}$

Data on spikelets $spike^{-1}$ were noted by taking five randomly selected spikes from each experimental unit and calculating the number of spikelets within each of the five randomly selected spikes and then averaging the values.

Grains $Spike^{-1}$

Data pertaining to grains $spike^{-1}$ were noted by selecting five spikes from every experimental unit randomly and counting the number of grains in the five randomly selected spikes and then averaging the values.

Thousand Grain Weight (g)

One thousand grains were counted from the seed lot of every experimental unit and then a sensitive electronic balance was used to weigh the grain sample to record the data.

Biological Yield (kg ha^{-1})

Five middle rows with three-meter length in each plot were harvested and then sun-dried for a week. Thereafter, the biomass was weighted with a digital scale and then converted to t ha^{-1} through the below formula:

$$\text{Biological yield}\left(t\ ha^{-1}\right) = \frac{Biological\ weight\ in\ kg/Five\ rows}{row - row\ distance \times row\ length \times no.\ of\ rows} \times 10 \quad (5)$$

Grain Yield (t ha^{-1})

The harvested material of five central rows with three-meter length in each plot after drying was threshed with a mini-thresher and cleaned of inert materials. Thereafter, the grains were weighed by a sensitive electronic scale and were then converted to t ha^{-1} through the below formula:

$$\text{Grain yield}\left(t\ ha^{-1}\right) = \frac{Grain\ weight\ \ in\ kg/Five\ rows}{row - row\ distance \times row\ length \times no.\ of\ rows} \times 10 \quad (6)$$

Harvest Index (%)

Harvest index was computed through the below formula:

$$\text{Harvest index}\ (\%) = \frac{Grain\ Yield\ \left(t\ ha^{-1}\right)}{Biological\ yield\ \left(t\ ha^{-1}\right)} \times 100 \quad (7)$$

2.5. Statistical Analysis

The collected data of various parameters were statistically analyzed as per the procedure relevant to the randomized complete block design with split plot arrangement. The treatment means were separated through the least significant differences (LSD) test at $p \leq 0.05$ [34]. Pearson correlation analysis was performed using the R program [35] to assess the relationship among different plant traits that varied among the genotypes.

3. Results

3.1. Phenological Attributes of Wheat Genotypes under Different Sowing Dates

Data regarding phenological attributes are given in Tables 2 and 3. Analysis of the data revealed that wheat genotypes and sowing dates significantly affected days to emergence, jointing, booting, heading, anthesis, and physiological maturity. The interaction between genotypes and sowing dates was not significant for all these attributes except days to physiological maturity. Wheat genotypes MY409-4, MY1501, and local variety PS-15 were found to be late in emergence, followed by MY1617, MY1416, MY291-4, MY1419, and MY902, which were found to be early in occurrence of emergence, while jointing, booting, heading, anthesis, and physiological maturity were delayed for MY1501, followed by MY1419 and MY902. Early jointing, booting, heading, anthesis, and physiological maturity were noted in genotypes MY2914 and local variety PS-15. The optimal sowing time delayed jointing, booting, heading, anthesis, and physiological maturity of all tested genotypes including the local check, while later sowing resulted in hastening of the occurrence of those phenological developments irrespective of wheat genotypes, excluding physiological maturity.

Table 2. Days to emergence, days to jointing, and days to booting of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Days to Emergence			Days to Jointing			Days to Booting		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
2020–2021	Local Check	13.3 f–h	15.7 b–d	17.0 ab	60.7 fg	61.0 fg	57.0 i	121.3 cd	109.7 hi	100 l
	MY1416	12.3 h–i	15.3 c–e	18.0 a	69.0 ab	66.0 cd	64.0 de	122 b–d	109.3 hi	102.7 kl
	MY1419	11.7 ij	14.0 e–g	17.0 ab	65.0 de	62.7 ef	59.0 g–i	123.3 a–d	115.3 fg	105 jk
	MY1501	11.0 j	13.7 f–h	17.0 ab	68.3 a–c	64.7 de	60.0 f–h	125.3 ab	116 ef	106 i–k
	MY1617	11.3 ij	14.3 d–f	17.0 ab	64.0 de	60.0 f–h	59.3 g–i	119.7 de	109.7 hi	102.7 kl
	MY2914	12.7 g–i	15.7 b–d	18.0 a	70.0 a	68.0 a–c	62.7 ef	126 a	120.3 cd	112 gh
	MY4094	11.3 ij	14.0 e–g	17.0 ab	66.7 b–d	62.7 ef	57.3 hi	123.7 a–c	116.3 ef	108.3 h–j
	MY902	12.3 h–j	13.7 f–h	16.7 a–c	64.0 de	62.7 ef	59.0 g–i	125.7 ab	115.3 fg	107 ij
2021–2022	Check	12.67 i–k	15.67 ef	18 c	58.3 g–i	59 f–h	55 j	118.3 a–d	106.7 gh	97 m
	MY1416	12.67 i–k	16.33 de	20 ab	66 ab	63 cd	61 d–g	118 b–d	105.3 g–i	98.7 k–m
	MY1419	11.67 kl	15 e–g	19 bc	62 de	59.7 e–h	56 ij	119.3 a–c	111.3 ef	101 j–l
	MY1501	12.67 i–k	15 e–g	19 bc	65.3 a–c	61.7 d–f	57 h–j	121.3 ab	112 e	102 i–k
	MY1617	11 l	15.33 ef	19 bc	60 e–g	56 ij	55.3 j	114.7 de	104.7 g–j	97.7 lm
	MY2914	13.67 g–i	17.67 cd	21 a	61 d–g	59.7 e–h	56 ij	121.7 ab	111.3 ef	103 h–j
	MY4094	12 j–l	14.67 f–h	19 bc	63.7 b–d	59.7 e–h	54.3 j	119.7 a–c	112.3 e	104.3 g–j
	MY902	13.33 h–j	14.67 f–h	18.67 bc	67 a	65 a–c	59.7 e–h	122 a	116.3 cd	108 fg
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

Table 3. Days to heading, days to anthesis, and days to physiological maturity of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Days to Heading			Days to Anthesis			Days to P. Maturity		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
2020–2021	Local Check	128.3 cd	116 ij	107 m	134 c	122.3 ij	112 n	165.3 ef	152.7 jk	141.3 p
	MY1416	128.7 cd	117.3 hi	108.7 lm	134.3 c	123.7 g–i	114.7 mn	171.3 d	158.3 i	145.3 no
	MY1419	129.7 b–d	121.7 fg	110.7 kl	134.7 bc	126 f–h	117 lm	174.3 c	161.3 gh	149 lm
	MY1501	133.3 a	123.3 ef	113.7 jk	138.7 a	128 ef	118.7 kl	172.7 cd	160.3 hi	147 mn
	MY1617	126.7 de	115 ij	107.3 lm	132.7 cd	120.7 i–k	113.7 mn	166.3 e	153.3 j	143.7 o

Table 3. *Cont.*

Y	Genotypes	Days to Heading			Days to Anthesis			Days to P. Maturity		
		Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
	MY2914	132.7 ab	127 d	119.7 gh	139 a	130.3 de	123 h–j	180.3 a	166.3 e	151 kl
	MY4094	131 a–c	123.3 ef	115 ij	138 ab	127.7 ef	119.7 j–l	176.7 b	163.3 fg	150 l
	MY902	132.7 ab	123 fg	113.3 jk	138.3 a	127 e–g	118.7 kl	177 b	163.7 f	149.7 l
2021–2022	Local Check	125 b–d	112.7 i–k	103.7 no	129.7 cd	118 i–k	107.7 o	161.3 e	148.7 j	137.3 o
	MY1416	124.3 c–e	113 ij	104.3 no	131.3 bc	122.7 f–h	113.7 lm	166.3 d	153.3 i	140.3 n
	MY1419	125.3 b–d	117.3 gh	106.3 mn	131 c	120.3 g–i	111.3 mn	169.3 c	156.3 gh	144 lm
	MY1501	129 a	119 fg	109.3 k–m	135.3 a	124.7 ef	115.3 kl	172 b	158.7 f	144.7 l
	MY1617	121.3 ef	109.7 j–m	102 o	128.3 cd	116.3 j–l	109.3 no	160.3 ef	147.3 jk	137.7 o
	MY2914	128.3 ab	118.7 f–h	109 lm	135 a	123.7 e–g	115.3 kl	175.3 a	161.3 e	146 kl
	MY4094	126.7 a–c	119 fg	110.7 j–l	134.7 ab	124.3 ef	116.3 j–l	171.7 b	158.3 fg	145 l
	MY902	128.3 ab	122.7 de	115.3 hi	135.7 a	127 de	119.7 h–j	167.7 cd	155.3 hi	142 mn
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

3.2. Growth Attributes of Wheat Genotypes under Different Sowing Dates

Data pertaining to emergence (m^{-2}), tillers (m^{-2}), and flag leaf area (cm^2) are presented in Table 4. Perusal of the data demonstrated significant variation among wheat genotypes and sowing dates for emergence (m^{-2}), tillers (m^{-2}), and flag leaf area (cm^2). The genotypes and sowing dates interaction was found to be significant only for the flag leaf area. The higher emergence (135 m^{-2}) occurred in genotype MY1617 during the first year and line MY1416 (122) during the second year when sown early, followed by MY2914 (127 and 114 m^{-2}) which was statistically similar to MY1419 (130 and 117 m^{-2}). Low emergence (76 and 68.3 m^{-2}) occurred in the local check (PS-15) during late sowing. Across genotypes, early sowing resulted in higher emergence than late sowing. Wheat genotype MY1617 produced more tillers (425 and 369 m^{-2}) followed by MY902 (409 and 383 m^{-2}) when sown early, while a lesser number of tillers (315 and 283 m^{-2}) was recorded for genotypes MY1416 and MY 4094 and the local check. In general, a wheat crop sown earlier resulted in a greater number of tillers in comparison with late sowing. A higher flag leaf area (49.2 and 41.2 cm^2) was recorded for the local cultivar PS-15 followed by MY1617 (44 and 36.6 cm^2) during early sowing, whereas the minimum flag leaf area (21.5 and 18 cm^2) was observed for line MY1416, which was statistically similar to all genotypes except the local check with greater leaf area during late sowing. Across sowing dates, a greater flag leaf area was recorded for early sowing on 1st November followed by 16th November, whereas a reduced flag leaf area was measured in late sowing on 1st December. Data on plant height, spike length, and spikes m^{-2} are presented in Table 5. Wheat genotype MY1617 produced taller plants (110.4 and 106 cm) during early sowing followed by the same genotypes when sown in the middle (104 and 100 cm) and MY1416 (99.7 and 94.2 cm) under early sowing. Short-statured plants (70.7 and 68.3 cm) were recorded for MY902, which were at par with MY4094 and MY2914 during late sowing. Generally, early sowing produced taller plants, whereas a delay in sowing produced short-statured plants.

Table 4. Emergence m^{-2}, tillers m^{-2}, and flag leaf area of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Emergence m^{-2}			Tillers m^{-2}			Flag Leaf Area cm^2		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
2020–2021	Local Check	92.6 f–h	83.0 hi	75.9 i	356 f–h	339 h–j	320 jk	49.2 a	39.7 bc	30.8 d–h
	MY1416	107.7 de	87 g–i	76.3 i	350 g–i	336 ij	315 k	34.6 c–f	30.3 e–i	21.5 l
	MY1419	129.6 ab	105.9 ef	78.9 hi	370 ef	348 g–i	322 jk	31.4 d–g	27.1 g–k	24.3 j–l
	MY1501	105.6 ef	103.3 ef	83.3 hi	374 d–f	351 g–i	321 jk	36.0 c–e	31.0 d–h	26.7 g–l
	MY1617	135.3 a	120.3 b–d	92.7 f–h	425 ab	410 ab	385 c–e	44.0 b	34.4 c–f	29.3 f–j
	MY2914	126.7 a–c	108.5 de	78.9 hi	390 cd	370 ef	347 g–i	26.9 g–l	25.7 h–l	23.3 kl
	MY4094	113.7 c–e	102.2 ef	82.2 hi	359 fg	344 g–i	315 k	28 g–k	24.9 i–l	23.5 kl
	MY902	110.4 de	100 e–g	82.2 hi	409 ab	396 bc	370 ef	36.0 cd	29.7 f–j	30.3 e–i
2021–2022	Check	83.3 f–h	74.7 hi	68.3 i	321 f–h	305 h–j	288 jk	41.2 a	33.2 bc	25.2 d–f
	MY1416	122 a	108.3 b–d	83.3 f–h	315 g–i	302 ij	284 k	25.5 d–f	24.2 d–g	18.0 h
	MY1419	116.7 ab	95.3 ef	71 hi	333 ef	313 g–i	289 jk	24.9 d–g	22.9 e–h	19.4 gh
	MY1501	95 ef	93 ef	75 hi	337 d–f	316 g–i	289 jk	26.9 de	23.6 e–h	22.9 e–h
	MY1617	96.7 de	78.3 g–i	68.7 i	369 ab	356 bc	333 ef	36.64 ab	24.4 d–g	24.2 d–g
	MY2914	114 a–c	97.7 de	71 hi	351 cd	333 ef	312 g–i	19.9 f–h	19.4 gh	24.5 d–g
	MY4094	102.3 c–e	92 ef	74 hi	323 fg	309 g–i	283 k	22.1 e–h	20.5 f–h	18.4 h
	MY902	99.3 de	90 e–g	74 hi	383 a	369 ab	347 c–e	29.5 cd	21.9 e–h	25.5 d–f
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

Table 5. Plant height (cm), spike length (cm), and spike m^{-2} of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Plant Height (cm)			Spike Length (cm)			Spikes m^{-2}		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
2020–2021	Check	97.4 d	92.86 e	83.8 gh	13.74 ab	12.22 b–e	10.77 e–g	332 g–j	314 j–l	297 lm
	MY1416	100.7 c	93.8 e	85.05 gh	11.71 c–e	10.98 ef	9.51 f–h	327 h–k	311 k–m	299 lm
	MY1419	92.72 e	86.02 fg	80.23 ij	11.32 de	13.09 a–c	9.09 gh	343 f–h	326 h–k	298 lm
	MY1501	85.13 g	79 j	70.93 k	9.49 f–h	8.61 hi	7.15 i	346 e–g	328 g–k	298 lm
	MY1617	110.4 a	104 b	92.47 e	14.38 a	12.87 a–d	11.42 c–e	394 a	384 ab	361 d–f
	MY2914	88.24 f	82.33 hi	72.93 k	11.86 c–e	11.13 d–f	9.39 f–h	363 c–e	341 gh	323 i–k
	MY4094	86.07 fg	80.73 ij	71.33 k	11.99 b–e	11.02 ef	9.08 gh	335 g–i	319 i–k	295 m
	MY902	82.39 hi	79.2 j	70.73 k	14.37 a	12.82 a–d	10.85 ef	381 a–c	369 b–d	346 e–g
2021–2022	Check	93.67 c	89.17 d	80.83 fg	11.83 b	10.73 cd	9.17 f	299 g–j	283 j–l	268 lm
	MY1416	94.17 c	89 d	81.17 fg	10.43 c–e	10 e	8.27 g	294 h–k	280 k–m	269 lm
	MY1419	87.63 d	82.77 ef	74.67 j	10.1 e	9.3 f	8 gh	309 f–h	293 h–k	268 lm
	MY1501	80.33 gh	76 ij	67.33 k	8.33 g	8 gh	6.43 i	311 e–g	295 g–k	268 lm
	MY1617	106 a	100.33 b	88.33 d	12.77 a	11.6 b	10 e	342 a–c	332 b–d	311 e–g
	MY2914	84.33 e	79.67 gh	68.33 k	10.33 de	10.33 de	8.5 g	327 c–e	307 gh	290 i–k
	MY4094	82 e–g	77 ij	66.33 k	11 b	10.1 e	7.5 h	301 g–i	287 i–k	265 m
	MY902	78 hi	75.67 ij	68.33 k	12.83 a	11.83 b	9.93 e	355 a	345 ab	325 d–f
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					

Table 5. *Cont.*

		Plant Height (cm)			Spike Length (cm)			Spikes m^{-2}		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

3.3. Yield and Yield-Related Attributes of Wheat Genotypes under Different Sowing Dates

Data on spike length and spikes (m^{-2}) are reported in Table 5, whereas data on spikelets $spike^{-1}$, grains $spike^{-1}$, and 1000 grain weight are given in Table 6. Wheat genotypes and sowing dates significantly affected spike length, spikes (m^{-2}), spikelets $spike^{-1}$, and grains $spike^{-1}$. The interaction between genotypes and sowing dates was significant only for grains $spike^{-1}$. Taller spikes (14.4 cm and 12.77 cm) were obtained by genotype MY1617 which was statistically at par with MY902 (14.4 cm and 12.82 cm) followed by genotype MY4094 during early sowing, while shorter spikes (7.2 cm) were recorded for genotype MY1501 when sown late. Two years average data indicated that across genotypes, early sown plots produced longer spikes while shorter spikes were produced in late sown plots. Likewise, the maximum number of spikes (394 and 342 m^{-2}) was noted for MY1617 followed by MY902 (381 and 355 m^{-2}) for early sowing, whereas fewer spikes (295 and 265 m^{-2}) were noted for MY4094. Generally, the maximum number of spikes was recorded for sowing on 1st November followed by 16th November, while the minimum number of spikes was noted for sowing on 1st December. Wheat genotypes MY2914 produced 23 and 21 spikelets $spike^{-1}$ followed by MY4094, MY1416, MY1501, MY1419, MY902, and the local check PS-15 during early sowing in both years, whereas the genotype MY1419 produced 17 spikelets $spike^{-1}$, at par with all genotypes during late sowing. Similarly, the maximum number of grains $spike^{-1}$ (77 and 70) was recorded for MY1617, which was statistically at par with the local check PS-15, followed by MY1416.

Table 6. Spikelets $spike^{-1}$, grains $spike^{-1}$, and thousand grain weight (g) of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Spikelets $Spike^{-1}$			Grains $Spike^{-1}$			1000-Grain Weight		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
2020–2021	Check	22.2 bc	20.13 g	17.33 ij	75.27 ab	68.53 c	64.6 d	58.5 a	53 bc	49 f–h
	MY1416	22.07 b–d	20.47 g	17.13 j	62.6 d–f	59 hi	53.87 kl	49 f–h	47 h–j	45.52 jk
	MY1419	21.33 d–f	19.13 h	17.07 j	62.93 de	59.73 e–h	57.6 h–j	49.7 e–g	50.85 c–f	48.82 f–h
	MY1501	22.7 ab	20.13 g	17.2 ij	74.6 ab	64.2 d	58.8 hi	56.9 a	51.65 b–e	46.92 h–j
	MY1617	23.3 a	20.33 g	18 i	77.2 ab	72.6 b	63.8 d	57.75 a	53.75 b	52.45 b–d
	MY2914	21.67 c–e	20.67 fg	17.8 ij	62.47 d–g	59.47 f–h	56.73 h–k	47.3 g–j	44.7 jk	43.97 k
	MY4094	22.33 bc	20.53 fg	17.6 ij	59.13 g–i	58 h–j	53.73 kl	48.52 f–i	46.08 i–k	43.97 k
	MY902	21.73 cd	20.87 e–g	17.6 ij	56 i–k	54.8 j–l	52.47 l	53.85 b	49.95 d–f	48.33 f–i
2021–2022	Check	20 a–d	18.7 ef	15 h	65.3 ab	61.3 bc	58.3 cd	54.77 a	48.77 bc	43.6 f–h
	MY1416	20.7 ab	18.7 ef	15 h	53.3 d–g	49.7 g–i	44.7 i–k	45.27 d–f	42.53 g–i	40.6 ij
	MY1419	19.3 c–e	17.3 g	15.3 h	56.7 c–f	48.3 g–i	48.7 g–i	45.7 d–f	46.35 c–e	43.82 e–h
	MY1501	20.3 a–c	18 fg	15.7 h	65 ab	51 e–i	50.3 f–i	52.9 a	47.15 cd	41.92 hi
	MY1617	21 a	19 d–f	16 h	70.3 a	66.3 ab	57 c–e	53.67 a	50.27 b	47.47 cd
	MY2914	20 a–d	19 d–f	16 h	52.3 d–h	49 g–i	46.3 h–k	43.3 f–h	40.2 ij	38.97 j
	MY4094	21 a	19 d–f	15.3 h	49.7 g–i	47.7 g–i	46.3 h–k	44.52 e–g	41.58 hi	38.97 j
	MY902	19.7 b–e	19 d–f	15.7 h	41 jk	47.3 g–j	40.3 k	48.68 bc	45.45 d–f	43.33 f–h
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					

Table 6. *Cont.*

		Spikelets Spike^{-1}			Grains Spike^{-1}			1000-Grain Weight		
Y	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

When sowing early, lower numbers of grains spike^{-1} (52 and 40) were noted for genotype MY902. In general, crops sown earlier resulted in more grains spike^{-1} in comparison with delayed sowing. Sowing on 1st November produced 66 grains per spike followed by 16th November. The local check produced heavier grains (58.5 g and 54.8 g), which was statistically at par with wheat genotype MY1501 and MY1617 when sown early, while lighter grains (43.97 and 38.97 g) were noted for genotype MY2914 and MY4094 when sown late. Early sowing resulted in heavier grains than delayed sowing.

Data pertaining to biological yield, grain yield, and harvest index are presented in Table 7. Wheat genotypes and sowing dates significantly influenced biological yield, grain yield, and harvest index of wheat. The wheat genotype MY1617 produced a higher biological yield (16.67 t ha^{-1}) during the first year, which was statistically at par with MY1419, MY1416, and the local check when sown early, followed by MY1501. The higher biological yield was produced by genotype MY1416 (15.69 t ha^{-1}) during the second year under early sowing, which was at par with MY1617, MY1419, and the local check. Minimal biomass yield (7.8 and 6.33 t ha^{-1}) was noted for genotype MY4094, which was statistically similar to the rest of the genotypes, excluding MY1416 (12.47 and 12.40 t ha^{-1}), followed by the local check under late sowing. The higher grain yield (6.03 and 5.51 t ha^{-1}) was obtained by genotype MY1617 under early sowing, followed by the local variety PS-15 (5.35 and 4.68 tha^{-1}), whereas the lowest grain yield (3.49 and 2.72 ha^{-1}) was noted for MY4094. In the case of the harvest index, the higher values (44.9%) were recorded for MY2914 during the first year under early sowing, which was statistically at par with MY902 and MY4094. The genotype MY1617 resulted in a higher harvest index (42.6%) under late sowing during the second year, which was at par with all studied genotypes except MY1416. The harvest index of both years revealed that all tested genotypes, excluding MY1416, resulted in a higher harvest index under late sowing, while the genotypes MY902, MY4094, MY2914, and MY1617 achieved a higher harvest index under mid sowing during both years.

Table 7. Biological and grain yields and harvest index of different wheat genotypes grown under the semi-arid climate of northern Pakistan.

		Biological Yield (t ha^{-1})			Grain Yield (t ha^{-1})			HI (%)		
Year1	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
	Local check	15.31 ab	11.98 c–f	11.23 d–g	5.35 ab	4.25 d–h	4.98 b–e	34.9 cd	35.5 cd	44.3 a
	MY1416	15.17 ab	12.59 b–f	12.47 b–f	5.24 abc	4.45 b–h	4.43 b–h	32.2 d	35.2 cd	35.8 cd
	MY1419	14.94 abc	13.70 a–d	8.89 g–i	4.78 b–f	4.72 b–f	3.90 f–h	32.5 d	36.0 cd	43.8 ab
	MY1501	12.47 b–f	11.48 d–g	8.89 g–i	5.05 b–d	4.07 e–h	3.94 f–h	40.7 a–c	36.2 cd	44.4 a
	MY1617	16.67 a	13.21 b–e	10.12 f–i	6.03 a	5.09 a–d	4.46 b–g	36.8 b–d	39.0 a–d	44.1 ab
	MY2914	10.87 d–h	11.24 d–g	8.15 hi	4.82 b–f	4.25 d–h	3.63 gh	44.9 a	38.4 a–d	44.6 a
	MY4094	11.98 c–f	9.63 f–i	7.78 i	4.83 b–f	3.96 f–h	3.49 h	40.1 a–c	41.8 a–c	45.1 a
	MY902	10.86 d–h	10.74 d–i	10.49 e–i	4.40 b–h	4.28 c–h	4.67 b–f	40.2 a–c	40.2 a–c	40.3 a–d
Year2	Local check	14.03 a–e	10.87 c–h	8.66 g–k	4.68 a–c	3.78 c–h	3.65 d–i	33.4 cd	34.7 cd	42.3 a
	MY1416	15.69 a	10.58 c–h	12.40 bc	4.79 ab	3.58 d–i	4.20 b–f	30.7 d	34.4 cd	33.8 cd
	MY1419	13.86 ab	12.04 b–d	7.45 i–k	4.22 b–f	4.05 b–g	3.12 g–i	31.0 d	35.3 cd	41.8 ab
	MY1501	11.53 b–f	9.79 c–i	7.47 i–k	4.49 b–d	3.41 e–i	3.16 g–i	39.2 a–c	35.4 cd	42.4 a

Table 7. *Cont.*

		Biological Yield (t ha^{-1})			Grain Yield (t ha^{-1})			HI (%)		
Year1	**Genotypes**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**	**Early**	**Mid**	**Late**
	MY1617	14.15 ab	11.87 b–f	8.64 g–k	5.51 a	4.42 b–d	3.68 d–h	38.9 b–d	37.7 a–d	42.6 a
	MY2914	12.03 b–e	9.55 jk	6.785 jk	4.26 b–e	3.58 d–i	2.85 hi	35.3 a	38.2 a–d	42.1 a
	MY4094	10.99 c–g	8.17 h–k	6.33 k	4.27 b–e	3.30 f–i	2.72 i	38.5 a–c	41.0 a–c	43.1 a
	MY902	9.85 c–i	9.20 e–j	9.14 f–k	3.84 c–g	3.62 d–i	3.89 b–g	38.7 a–c	39.5 a–c	42.3 a
	SOV									
	Year	**	**		ns					
	MSD	**	*		**					
	MSV	*	**		**					
	MSDxV	ns	ns		*					

SOV = source of variance, MSD = mean square for sowing dates, MSV = mean square for genotypes, * significant at 5% level of probability, ** significant at 1% level of probability, ns: non-significant. Means in columns followed by different letters are significantly different from each other at 5% level of significance based on the LSD test.

3.4. Correlation Analysis

Pearson's correlation analysis was used to identify relationships between different morpho-physiological attributes of wheat genotypes under early to late sowing times (Figure 1). Grain yield was positively correlated with GPS, days to anthesis, booting, and heading, while positive weaker values correlated with days to emergence, maturity, and jointing; however, no significant correlation was found with spikelets per spike. The negative correlation was found with plant height, biological yield, spike length, and flag leaf area. These correlations indicate a close relationship between the genotypes under late planting.

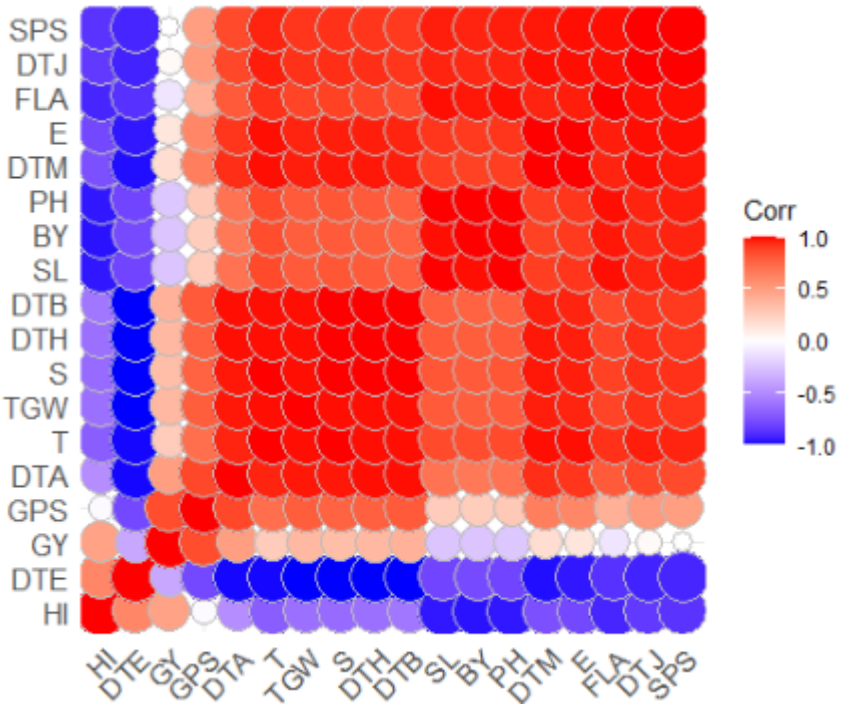


Figure 1. Correlation plot for the studied traits of different wheat genotypes as influenced by sowing dates. HI = harvest index, DTE = days to emergence, GY = grain yield, GPS = grains per spike, DTA = days to anthesis, T = tillers m^{-2}, TGW = thousand grain weight, S = spike m^{-2}, DTH = days to heading, DTB = days to booting, SL = spike length, BY = biological yield, PH = plant height, DTM = days to physiological maturity, E = days to emergence, FLA = flag leaf area, DTJ = days to jointing, SPS = spikelets per spike.

Principal Component Analysis (PCA)

PCA loading plots were prepared to measure the effects of sowing time on the various growth parameters of wheat genotypes (Figure 2). The responses of the different parameters to wheat genotypes sown under early to late planting were visualized as PC1 (principal component 1) and PC2 (principal component 2). PC1 and PC2 explained 58.1% and 17.6% of the total variance (Figure 2). The PCA results indicated a clear separation between the genotypes with respect to growth and morpho-physiological parameters under different sowing dates. PC1 was positively correlated with DTE and HI MY4094 under late planting and was very negatively correlated with plant height, GPS, spike length, tillers, and spikes m^{-2}, BY, and GY. The PC2 was positively correlated with spikelets per spike, days to jointing, booting, heading, anthesis, and maturity for exotic genotypes under early planting.

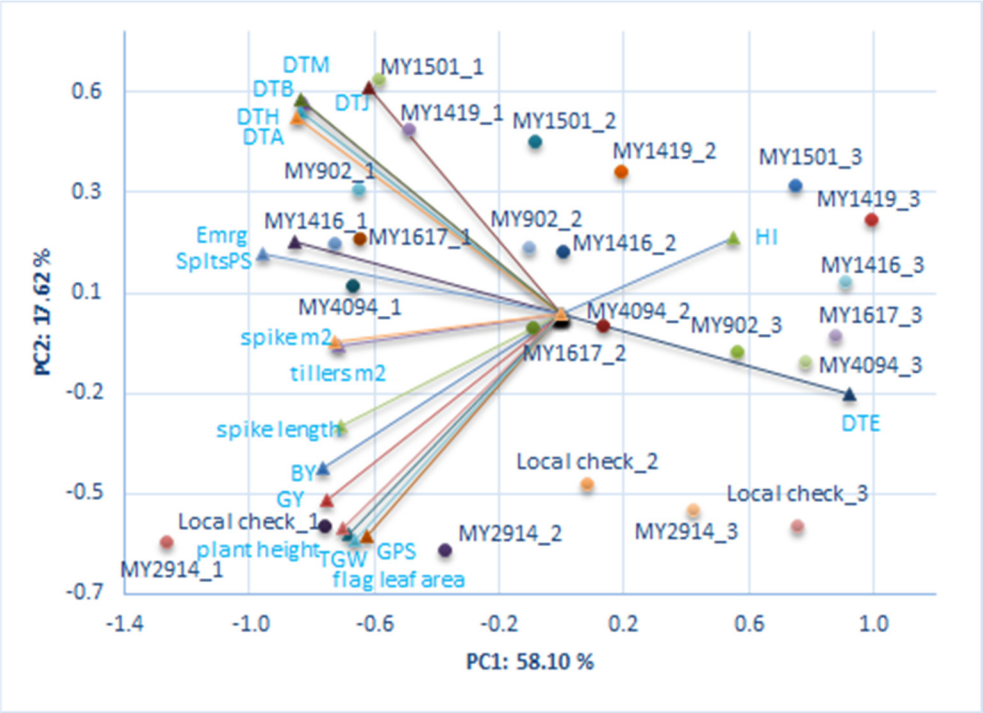


Figure 2. Bi-plot (PCA) presenting the correlation between the studied traits of different wheat genotypes sowing from normal to late planting. DTE = days to emergence, DTJ = days to jointing, DTB = days to booting, DTH = days to heading, DTA = days to anthesis, DTPM = days to physiological maturity.

4. Discussion

Normal and late-planted wheat genotypes showed significant differences in crop emergence and time to phenological events (days to jointing, booting, heading, anthesis, and physiological maturity). Normal planting performed better than late planting for all genotypes except genotype MY902. Early planting delayed wheat jointing, booting, heading, anthesis, and maturity. Awan et al. [17] found that low temperatures slowed germination when sowing on 25th December. Variation in days to emergence may also be due to temperature differences between early planting on 15th October and late planting on 14th November [36]. Mid-November sowing led to earlier jointing, booting, heading, anthesis, and physiological maturity, according to Akmal et al. [37]. Similarly, Upadhyaya and Bhandari [38] reported that late-sown wheat on 30th December faced unfavorable environmental conditions at each developmental stage, reducing crop life. Each crop has temperature and solar radiation requirements for emergence, growth, and heading [39]. Likewise, Sial et al. [7] reported that late sowing during December resulted in earlier booting due to a 30 °C rise in March. Previously, Shahzad et al. [40] also suggested that delayed sowing on 16th January exposed the crop to cooler temperatures during emergence, result-

ing in delayed emergence, early heading, and anthesis. Tahir et al. [41] reported that late planting on 25th December resulted in early anthesis due to higher temperatures shortening the growing period. Early planting on 25th October prolonged the life cycle in which the plants completed their vegetative growth in optimal temperature, resulting in good grain filling and physiological maturity in comparison to late planting on 15th December. Due to genotypic variability and germination potential, Suleiman et al. [42] and Tahir et al. [12] found differences in wheat genotype for emergence. Likewise, Araus et al. [43] showed that variation in wheat phenological development stages may be due to climate. Wheat genotypes differ in days to heading due to genetic makeup [44]. Likewise, Anwar et al. [45] suggested that the genetic potential of varieties to use available resources efficiently may affect their maturity.

Wheat genotypes sown at different times differed in tillering capacity, flag leaf area, and tiller height. MY1617 followed by MY1419 and MY2914 resulted in higher emergence under early sowing, whereas later sowing dates reduced emergence of all genotypes under study. Maximum emergence in early sowing may be due to the optimal temperature required for better emergence, resulting in good crop growth and development later in the crop's life. Cooler temperatures reduced emergence from 1 to 20 November [46]. MY1617 produced more tillers under early and mid-sowing followed by MY902 when sown early, indicating better adaptability compared to the rest of the genotypes. Soil nutrients, environmental conditions, and genotype genetics affect wheat emergence and tiller count [47,48] Similarly, Bhattarai et al. [49] reported that late-sown plots (15th December) had fewer productive tillers in February. Heat causes scorching, twigs, senescence, and leaf abscission [50].

We found taller plants in the genotype My1617 under both early and mid-sowing, followed by MY1416. Likewise, early sowing resulted in greater flag leaf area than mid and late sowing. Temperatures above 30 °C in late sowing reduced leaf blade area, photosynthetic activity per unit leaf area, and source–sink relationship. Genetic potential affects wheat flag leaf area [51]. We also found that genotype MY1617 was taller than the rest of the genotypes under late sowing as well. Late-sown wheat grows shorter in unfavorable conditions, according to Nizamuddin et al. [52]. Short-statured plants may be due to delayed planting, whereas crops grown earlier benefited more from solar radiation and temperature [38]. Climate affects plant height genetically, according to Bhutta et al. [53] and Tillet et al. [54], who reported that genotype traits and climate can affect wheat plant height. Genetics can also affect plant height [55].

Wheat genotypes and sowing dates significantly affected spike length, number, spikelets spike^{-1}, and grains spike^{-1}. MY902 and MY1617 had long spikes during early sowing compared to the rest of the genotypes, indicating its improved genetic inheritance. Across genotypes, late sowing resulted in shorter spikes due to high temperature and the longer daily photoperiod reducing growth [56]. Optimal planting time led to superior spike development due to a longer growing phase, according to Baloch et al. MY1617 followed by MY902 had more spikes and spikelets per spike than the rest of the genotypes when sown under early sowing dates. Across genotypes, late sowing produced fewer spikes due to a shorter growing phase, according to Malik et al. [57]. Early sowing may produce more spikes due to optimal temperature and high photosynthate accumulation [58,59]. In the present study, late sowing shortened the growing season of crops, resulting in less photosynthate and sterility of spikelets during grain filling, which decreased spikelets spike^{-1}. Variation in the number of spikelets spike^{-1} in some wheat varieties may be due to shorter spikes, due to its genetically controlled inheritance [60]. We found that the local check, MY1617, and MY1501 genotypes produced more grains per spike when sowing early, while later sowing resulted in a reduced number of grains for all genotypes. A longer diurnal photoperiod and higher temperature at the reproductive stage may reduce grain spike^{-1} [61]. Likewise, Tahir et al. [41] also reported that the reduction in yield components in late sowing may be due to temperature increases that reduce growing degree days, photosynthetic active radiation, and the source–sink relationship. Differences in wheat

cultivar spike length, number of spikes, and grains per spike may be due to genotypic variation. In a similar way, Khan [22] also reported that grains per spike are linked with crop biomass and leaf area.

In the present study, the local check, MY1617, and MY1501 wheat genotypes produced heavier grains. We also found that early sowing across genotypes yielded heavier grains, while delayed sowing yielded lighter and shriveled grains. Late-sown crops reduce grain filling and weight [62]. The increase in temperature during the late planting's reproductive stage reduces grain weight by shortening grain filling [63]. Variation in grain weight among genotypes may be due to genetic potential and climatic conditions, especially during grain filling. Water and nutrient use efficiency affect grain weight variation [64,65]. The genotypes MY1416, MY1617, and the local check PS-15 produced higher biological and grain yield than the rest of the genotypes under early sowing, whereas the genotype MY1416 produced a higher biological yield and the local check produced a higher grain yield which was at par with MY1416 and MY902 under late sowing compared to the rest of the genotypes, indicating their better potential under later sowing. Late-sown crops exposed to high temperatures and other unfavorable conditions reduce assimilate transfer to the kernel, plant growth, and tiller production [66]. Earlier sowing increased spikes m^{-2}, grains $spike^{-1}$, and grain weight [11]. Wheat yield variation may be due to assimilate translocation to the reproductive body, which is genetically determined. The MY2914 harvest index was higher under early sowing and MY1617 resulted in a greater harvest index under late sowing, indicating the improved potential of the genotype. Late planting (15th December) may reduce grain yield more than biological yield [17]. Wheat varieties genetic potential affects the harvest index, according to Mushtaq et al. [48]; later sowing accelerates development by shortening the juvenile and grain filling stages, reducing biomass production, translocation, grain number, and yields.

5. Conclusions

Grain yield penalties due to later sowing were ranged from 15 to 21% depending on genotype and sowing time during both years. The Chinese genotype MY2914 and our local cultivar PS-15 showed superior performance in terms of growth rate, leading to improved morpho-physiological development, which led to enhanced dry matter production and seed yield during timely sowing; however, delay in sowing substantially reduced growth of all tested genotypes, excluding genotype MY902, which was found to be better when sown late in the season, indicating superiority for late planting in the season. Overall, late planting resulted in a decrease in biological yield and grain yield. The exotic genotypes can be employed for boosting the yield of wheat and need to be incorporated in the future wheat breeding program. Moreover, cultivar and sowing date selection are effective strategies to mitigate the negative effects of climate change on wheat production in the country. This paper gives essential advice to breeders regarding cultivar selection and the choice of varieties and sowing dates for farmers in actual production.

Author Contributions: Conceptualization, B.K., M.A. and S.Z.; software, M.A., F.M. and E.W.-G.; formal analysis, F.M., E.W.-G. and M.M.A.; investigation, B.K., M.M.A. and M.A.; resources, M.A., Y.R., C.Z. and X.L.; data curation, M.A. and B.K.; writing—original draft preparation, B.K., F.M. and A.K.; writing—review and editing, M.A., S.Z. and Y.R.; visualization, M.M.A. and I.A.; supervision, M.A. and S.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (NSFC), grant number: 31661143018.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: The authors are highly thankful to the University research farm for provision of all inputs to conduct the experiment. The authors also highly appreciate our Chinese partners for provision of the Chinese wheat elite lines.

Conflicts of Interest: All authors declare that they have no conflict of interest.

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