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GENOTYPIC EFFECT OF MORPHOPHYSIOLOGICAL, SEED YIELD, AND YIELD QUALITY ATTRIBUTES OF SOYBEAN (*GLYCINE MAX*. (L.) MERRILL) ACROSS DIVERSE SOWING TIMES

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Abstract

A two-year field study was conducted to evaluate the impact of different sowing times on the development and production of seven distinct soybean genotypes, taking into account the potential effects of drought and high temperatures. The yield and morpho-physiological characteristics of various seeding periods were used to gauge how different genotypes of soybean responded. Four sowing dates and seven genotypes of soybean were used in the study. The study was comprised of different treatments; i) soybean genotypes; NARC-2, NARC-16, Faisal Soy, Ajmeri, Rawal, Malakand-96 and Swat-84 ii) sowing dates (1st week of July, 3rd week of July, 1st week of august and 3rd week of august). The study was carried out over two consecutive years to discern variations among genotypes. Results have revealed that sowing time significantly affected the phenological and growth attributes, including days to 50% emergence, days to flowering, pod formation, and maturity. In addition, early-sown crops showed better growth and development attributes as compared to late-sown crops. In comparison to early-sown crops, plant physiological parameters such as photosynthetic rate, transpiration, stomatal conductance, water potential, and relative water contents were similarly lower under late-sown crops. Additionally, the sowing time had an impact on seed output and yield qualities, with early-planted crops showing higher seed weight and yield than late-planted crops. Among the genotypes, soybean genotype Malakand-96 was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and minimum seed oil content was measured in soybean genotype NARC-16. Malakand-96 showed maximum morphophysiological, seed yield attributes, and seed quality parameters as compared to other genotypes, however, Faisal soy stood second in terms of performance under early and late sown crops. Superior genotypes are selected for more study and development. These genotypes can be directly applied to areas where drought and high temperatures are common, or they can be utilized as parents in breeding initiatives to create varieties that can withstand the combined pressures of high temperatures and drought.

Keywords: Sowing Time, Genetic Potential, Phenology, Physiology, Quality.

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INTRODUCTION

A dicot, short day, C_3 legume crop high in protein and oil, soybeans account for 25% of the world's vegetable oil production (Parasuraman *et al*., 2024) and grown on 103 million hectares worldwide, yielding an annual production of 261 million tonnes and average productivity of 2533 kg ha^{-1} contributing up to 25% of the world's vegetable oil production (Parasuraman *et al*., 2024; Mandi *et al*., 2017). According to area, the top producing nations for soybeans are the US, Brazil, Argentina, China, India, and Paraguay (Sedibe, 2023). Production of soybean oil in Pakistan rose from 240 tonnes in 2016 to 260 tonnes in 2017. (USDA, 2017). On the other hand, one of the main reasons soybean yield loss occurs during plant growth and development is unfavourable environmental circumstances. Due to a sharp rise in population and shifting dietary habits, Pakistan is facing increasingly economic difficulties, which is driving up demand for edible oils. Pakistan spent 3.681 billion US dollars in foreign exchange on edible oil imports, covering 80% of the nation's total domestic needs, while local output contributed only 20% (Govt. of Pakistan. 2022; Ahmad *et al*., 2022). However, the lack of soybean cultivation in the country is linked to challenges such as low adaptability, insufficient production technology, the need for locally adapted genetic material, the absence of solvent and processing industries, and a poorly developed marketing system (Govt. of Pakistan. 2022). However, unfavorable climatic conditions during plant growth and development are one of the leading causes of soybean yield loss. In the field, soybeans are subjected to a variety of stressors that negatively impact plant physiological functions and reduce output (Parasuraman *et al*., 2024). The most extensively grown grain legume in the world, soybeans are essential for the world's supply of both oil and protein (Kumar *et al*., 2021).

Nonetheless, prior research has indicated that throughout the vegetative and reproductive growth stages, the ideal temperature is 30°C and 25°C, respectively, because soybeans are extremely sensitive to temperature (Ahmad *et al*., 2021 a, b, c, d). While there have been some positive effects of global warming, rising air temperatures have also been shown to accelerate crop development (Liu *et al*., 2021) and increase the frequency of extreme weather events, both of which have been shown to negatively impact soybean yields (Zhao *et al*., 2021). A previous study found that the worldwide soybean yield decreased by 1.3% for every 1°C increase in mean temperature (Zhao *et al*., 2017). A 1°C increase in temperature can result in a 17% reduction in soybean yield when the temperature reaches 30°C. Furthermore, when extreme heat occurs in conjunction with a water deficit or drought, it can have compounding effects on yield reduction (Zhang *et al*., 2016). Effective crop management decisions play a pivotal role in ensuring successful cultivation and determining productivity, particularly in challenging environmental conditions, while the temperature in Pakistan exceeds 45°C during summer (Rurinda *et al*., 2015). Elevated temperatures during anthesis adversely affect pollination and grain development, resulting in a shortened grain-filling duration and decreased crop yield (Ahmad *et al*., 2020; dos Santos *et al*., 2022). Due to variations in temperature, precipitation, relative humidity, soil moisture content and photoperiod, sowing time has an impact on the phenological phase of the plant and consequently on the growth,

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development and yield of soybean (Jumrani and Bhatia, 2018). Weather fluctuations significantly impact crop phenology, affecting stages like leaf development, anthesis, and fruit production (Ahmed *et al*., 2019; Bhattacharya, 2022). Nonetheless, a number of studies have indicated that late planting may increase the protein content of soybean seeds since high temperatures tend to increase protein content with little to no effect on oil content (Mourtzinis *et al*., 2019; Bellaloui *et al*., 2015).

Furthermore, the full potential of soybeans genetically depends on the application of agricultural methods and technologies; in this regard, the right sowing time is critical to soybean output without increasing costs (Mandić *et al*., 2020). Cultivar variation in heat stress tolerance may provide a pathway for climate adaptation in the future (Li *et al*., 2022). Zheng *et al*. (2024) found that whereas low-yielding cultivars showed a considerable yield loss due to heat stress, high-yielding genotypes are comparatively well adapted to heat stress. Furthermore, using agricultural practices and technology is necessary to fully utilize the genetic potential of soybeans. In this regard, planting soybeans at the right time of year is crucial to output and does not increase costs (Mandić *et al*., 2020). Through cultivar variety, genetic resistance to heat stress could provide a means of climate adaptation in the future (Li *et al*., 2020). The purpose of this study was to ascertain how the planting time in two consecutive years affected the morphological, productive and quality attributes of seven genotypes of soybean cultivated in Punjab, Pakistan, specifically in Faisalabad. Therefore, the study aimed to evaluate how the interaction between sowing time and genotype impacts the morpho-physiological traits, seed yield and quality parameters in soybean. This characterization serves as a foundation for developing a futuristic roadmap that outlines the adaptability of soybean genotypes providing essential guidance for future cultivation practices.

MATERIALS AND METHODS

A field experiment was performed at the Department of Agronomy research area, University of Agriculture Faisalabad (31.25° N, 73.09° E, 184 m elevation) for two consecutive years whereby characterization of different soybean genotypes was done to screen suitable and viable cultivars regarding agronomic and phenological parameters in addition to quality parameters for further experiments. The region is considered semi-arid and subtropical according to the agroecological zones of Punjab (FAO, 2019). This experiment was conducted under a randomized complete block design (RCBD) with three replications. Sowing for this experiment took place from 1st week of july through 3rd week of august in both 2017 and 2018. The soil survey showed that the soil texture was loamy (Table 1). The environmental conditions of both years showed the maximum and minimum temperature, rainfall, and relative humidity (Table 2). The gross plot size for both was 4.0 m × 1.8 m. The fertilizer application included 25 kg N and 50 kg P ha^{-1} was applied. Uniform management practices were executed for all treatments, and the experiment was repeated across two years. The land was cultivated repeatedly for 2-3 times and then planked to create a fine seedbed. A farm tractor was used to perform these operations. To ensure optimal moisture levels, pre-soaking irrigation was applied

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before seedbed preparation. Throughout the entire crop cycle, significant efforts were made to manage weed, insect, and plant pathogen pressures through plant protection measures. Integrated operations were primarily employed to maintain weed-free conditions in the trials.

Table 1: Soil survey of experimental site during years (2017 & 2018)

Soil properties	Depth of sample (cm)	Years	
		2017	2018
Sand (%)	0-15	45	49
	15-30	45	46
Silt (%)	0-15	23	27
	15-30	21	23
Clay (%)	0-15	28	28
	15-30	32	33
Texture	0-15	Loam	Loam
	15-30		
E.C (dS m^{-1})	0-15	1.87	2.11
	15-30	1.98	2.03
pH of the soil	0-15	7.8	7.6
	15-30	7.7	7.8
OM (%)	0-15	0.62	0.78
	15-30	0.52	0.58
Nitrogen (%)	0-15	0.042	0.058
	15-30	0.041	0.049
P availability (mg kg^{-1})	0-15	7.3	7.8
	15-30	7.1	7.7
K availability (mg kg^{-1})	0-15	191	200
	15-30	162	182
Zinc (ppm)	0-15	0.60	0.65
	15-30	0.53	0.60
Boron (ppm)	0-15	0.39	0.49
	15-30	0.42	0.49

Table 2: Monthly averages of weather elements for soybean growing season

Weather conditions in Faisalabad			
	Mean Monthly Temperature (°C)	Rainfall (mm)	Sunshine Hours
2017			
July	32.5	92	214.3
Aug	32.5	17.6	234.9
Sep	30.2	29.6	259.2
Oct	27.4	0	231.4
Nov	17.6	Trace	124.8
2018			
July	31.8	123.8	236.1
Aug	32.8	25	237.2
Sep	30.7	33	251.2
Oct	25.7	1	240.3
Nov	19.7	Trace	183

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The time to 50% emergence (E50) was obtained using the formula given by Coolbear *et al*. (1984) amended by Farooq *et al*. (2005)

$$\text{E50} = \text{ti.} + \frac{[\frac{N}{2} - n]}{n.j - ni} + tj - ti$$

From each experimental plot, five plants were selected at random, and their height was measured using a measuring rod that went from the soil's surface to the tips of the crop plants. The average height of each plant was then determined. Five random plants were selected to count several branches per plant from each experimental unit. The gaseous exchange from the top third leaf of each plant was monitored between 9:00 and 11:00 a.m. using a photosynthetic recording system and a CI-340 portable infrared gas analyzer (Analytical Development Company, Hoddesdon, England). The leaf surface had an ambient CO_2 content of 352 mol mol^{-1}, the ambient temperature was between 22.4 and 27.9 °C, the leaf temperature ranged from 28.4 to 32.4 °C, the molar flow of air per unit leaf area was kept at 403.3 mmol m^2 s^{-1}, and the atmospheric pressure was 99.9 KPa as followed by Ahmad et al. (2021a). For every treatment, the fully developed youngest leaf was used to measure the leaf water potential (Ψw) from 8:00 to 10:00 a.m. in the morning, data were collected using a pressure chamber of the Scholander type (ARIMAD-2, ELE-International). The same leaves were thawed, crushed with a glass rod to extract the cell sap and then frozen at -20 °C to determine the osmotic/solute potential (Ψs). That sap was sucked with a disposable syringe so that an osmometer could measure the osmotic potential (Wescor-5500). The difference between ψw and ψs was used to determine the pressure potential or ψp. Following the collection and washing of plant leaves, the relative leaf water contents (RWC) were determined by weighing the fresh material using a digital electrical balance (Shimadzu AW-320, 161 Kyoto, Japan). The leaf samples were removed from the test tubes, dried using tissue paper, and weighed to find their turgid weight after being immersed in distilled water for 24 hours (TW). The same leaf samples were oven-dried for 72 hours at 65 °C (Memmert-110, Schwabach, Germany) in order to calculate the dry weight (DW). The RWC was calculated using the following formulas (Pask *et al*., 2012)

$$RWC = (\text{FW} - \text{DW}) \;/\; (\text{TW} - \text{D}) \times 100$$

The purpose of collecting the samples was to measure the amount of chlorophyll. The leaves of plants that had been marked at random were clipped off using scissors. The chlorophyll content was measured using fresh soybean leaf samples using the Arnon (1949) and Davies (1950) methods (1976). Fresh sample leaves were cut into 0.5 cm pieces, weighing 0.1g sample was crushed in 10mL of 80 percent acetone at 0°C. Next, the removed leaves were centrifuged at 15,000 rpm for 5 minutes. The absorbance of chlorophyll was determined using a spectrophotometer at 663, 645, and 480 nm, respectively. (Hitachi, 220, Japan).

$$\text{Total Chl} = [20.2\ (\text{OD}\ 645) + 8.02\ (\text{OD}\ 663)]\ \text{x}\ \frac{\text{V}}{100}\ \text{x}\ \text{W}$$

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The number of plants in each experimental unit were counted using a quadrate (1 m^{-2}) at the time of harvest. Five randomly chosen plants per plot were used to count the number of seeds from each pod. A digital electronic scale (Shimadzu AW-320, Kyoto, Japan) was used to weigh three representative samples of 1000 seeds from each experimental unit. The samples were subsequently oven-dried at 70 °C (Memmert-110, Schwabach, Germany) and converted to an average 1000 seed weight (Test weight) in grammes. After reaching the R8 stage (harvesting maturity) the crop was harvested at different times with the variation due to management issues and dried under the sun for a few days, threshed and seed yield was measured in kg ha^{-1}. The seed yield of every plant was recorded, and the total seed production was used to determine the protein and oil content of the seeds. To ascertain the oil content, the Soxhlet fat extraction method (AOAC, 1990) was employed. The calculation of oil yield (kg $plant^{-1}$) involved multiplying the seed yield by the percentage of oil content. The Kjeldahl method (Bremner, 1964) was used to calculate the nitrogen concentration of seeds to ascertain their protein content. Using acid-based titration, the percentage of crude protein was determined by multiplying the acid volume used by a factor of 6.25.

Statistical analysis

Using the statistical software statistics 10.1, the data was examined and means were compared using the LSD (Least Significant Difference Test) at a significance threshold of five percent (Steel *et al*., 1997).

RESULTS

Phenological parameters

Table 3: Treatments/Genotypes

Factors	Treatments
Soybean genotypes	G1= NARC-2 G2= NARC-16 G3= Faisal Soy G4= Ajmeri G5= Rawal G6= Malakand-96 G7= Sawat-84
Sowing dates	SD1= 6th July SD2= 21st July SD3= 4 August SD4= 19 August
Replications	3

Results have revealed that soybean genotypes and sowing dates showed a significant ($P < 0.05$) on plant phenological attributes, including days to 50% emergence, mean emergence time, emergence index, days to flowering, days to pod formation, days to maturity, and plant population during both years of study (Table 4). Among the different genotypes, a significant difference among different genotypes was revealed.

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Soybean genotype Malakand-96 performed better as compared to other genotypes followed by Faisal Soy, Ajmeri, Sawat-84, Rawal, NARC-2, and NARC-16. Among different sowing dates, 6th July showed maximum performance as compared to other sowing times including 21st July, 4 August, and 19 August, respectively. The interactions among soybean genotypes and sowing times were significant for all the phenological parameters. In addition, soybean genotypes showed better phenological growth in the year 2017 as compared to 2018.

Table 4: Effect of different sowing times on the morpho-phenological attributes in soybean genotypes

Treatments		Days to 50% emergence		Days to flowering		Days to pod formation		Days to maturity		Plant population		Plant height (cm)	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Sowing dates	SD1	4.97a	5.17a	3.15a	53.3a	60.9a	63.7a	3.15a	97.0a	19.0a	19.3a	46.5a	50.6a
	SD2	4.81b	5.09b	2.95b	50.8b	58.2b	59.6b	2.95b	94.8b	18.2b	18.7b	44.9b	47.7b
	SD3	4.74bc	4.88c	2.82c	49.6b	54.1c	56.7c	2.82c	92.0c	17.4c	18.2b	43.4c	46.4b
	SD4	4.65c	4.81c	2.67d	48.0c	51.3d	53.8d	2.67d	89.9d	16.7d	17.6c	41.6d	44.4c
LSD (*P < 0.05*)		**0.10**	**0.07**	**0.03**	**1.31**	**1.37**	**1.41**	**0.03**	**1.88**	**0.49**	**0.55**	**1.40**	**1.24**
Genotypes	G1	4.86a	5.07a	2.66e	48.3c	51.8e	53.8c	2.66e	89.7d	16.9d	17.3e	37.9e	37.0e
	G2	4.86a	5.11a	2.60f	46.4d	48.2f	53.8c	2.60f	86.9e	16.7d	16.0f	37.7e	35.8e
	G3	4.76ab	4.88cd	3.16b	53.9b	59.9b	60.3b	3.16b	98.5b	18.3b	19.5b	49.0b	54.9b
	G4	4.75ab	4.94bc	3.06c	49.5c	57.9c	60.0b	3.06c	93.8c	18.0b	19.0bc	46.7c	50.3c
	G5	4.83ab	5.05a	2.75d	48.7c	53.6d	59.4b	2.75d	89.5d	17.3cd	18.0d	40.9d	42.9d
	G6	4.71b	4.83d	3.27a	57.2a	64.7a	63.0a	3.27a	103.2a	19.8a	20.9a	54.4a	61.3a
	G7	4.78ab	5.01ab	2.79d	49.1c	57.0c	58.8b	2.79d	92.4c	17.8bc	18.5cd	41.9d	48.8c
LSD (*P < 0.05*)		**0.14**	**0.10**	**0.05**	**1.74**	**1.81**	**1.87**	**0.05**	**2.49**	**0.65**	**0.73**	**0.78**	**1.87**

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal, G6= Malakand-96. G7= Sawat-84. LSD= Least significant difference; Values sharing the same case letter or without lettering, for a parameter, do not differ significantly ($P \leq 0.05$) by the LSD test.

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Physiological parameters

Gas exchange parameters

Results have revealed the significant ($P < 0.05$) effect of sowing time and soybean genotypes on plant physiological parameters. Analysis of variance showed that soybean genotypes showed a significant variation among plant physiological attributes, including photosynthetic rate (*PN*), transpiration rate (*TR*), and stomatal conductance (*gs*) (Figs 1-3). Maximum values of *PN*, *TR*, and *gs* were observed in genotype Malakand-96 followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and NARC-16 respectively. Among the sowing dates, 6th July showed maximum *PN*, *TR*, and *gs* followed by 21st July, 4 August, and 19 August, respectively. The interactions among soybean genotypes and sowing times were significant for all the gas exchange parameters. In addition, soybean genotypes showed better *PN*, *TR*, and *gs* in the year 2017 as compared to 2018.

Water relations

Results have revealed the significant ($P < 0.05$) effect of sowing time and soybean genotypes on plant water relations. Analysis variance showed that soybean genotypes showed a significant variation among water relation attributes, including water potential (*WP*) and relative water content (*RWC*) (Figs 3-4. Maximum values of *WP* and *RWC* were observed in genotype Malakand-96 which was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and NARC-16, respectively. Among the sowing times, sowing time-6th July showed maximum WP and RWC in soybean genotypes followed by 21st July, 4 August, and 19 August, respectively. The interactions among soybean genotypes and sowing times were significant for all the water relations. In addition, soybean genotypes have shown better water potential and relative water content in the year 2017 as compared to 2018.

Chlorophyll content

Results have revealed the significant ($P < 0.05$) effect of sowing time and soybean genotypes on plant chlorophyll content. Analysis variance showed that soybean genotypes showed a significant variation in chlorophyll contents and maximum chlorophyll content was measured in genotype Malakand-96 which was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and NARC-16, respectively (Fig 6). Among the sowing times, sowing time-6th July showed maximum chlorophyll contents which was followed by 21st July, 4 August, and 19 August, respectively. The interactions among soybean genotypes and sowing times were significant for the chlorophyll content. In addition, soybean genotypes showed better chlorophyll content in the year 2017 as compared to 2018.

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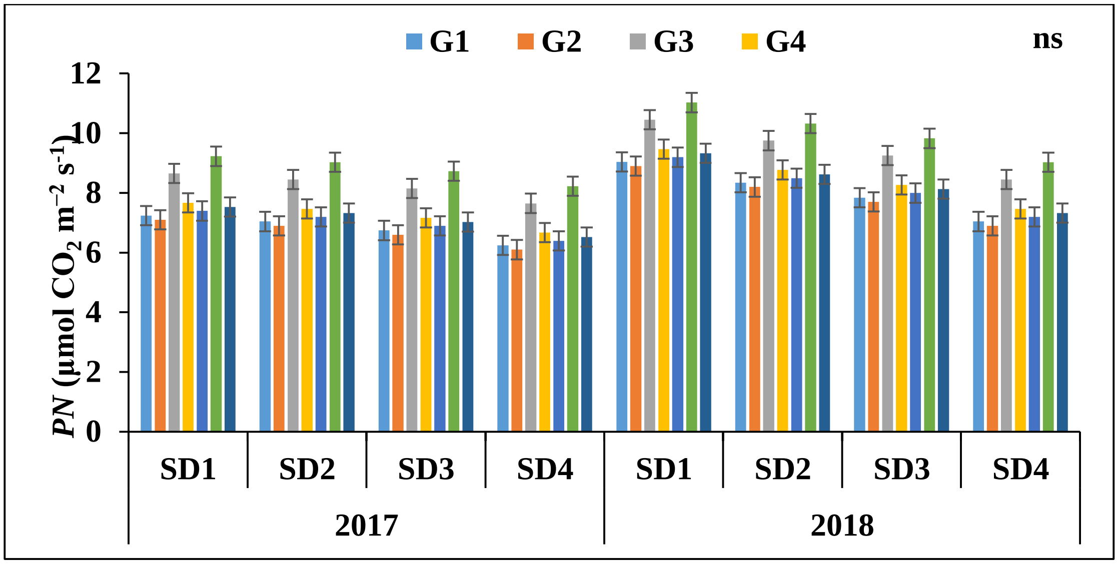

Fig 1: Effect of different sowing times and genotypes on photosynthetic rate (*PN*) in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

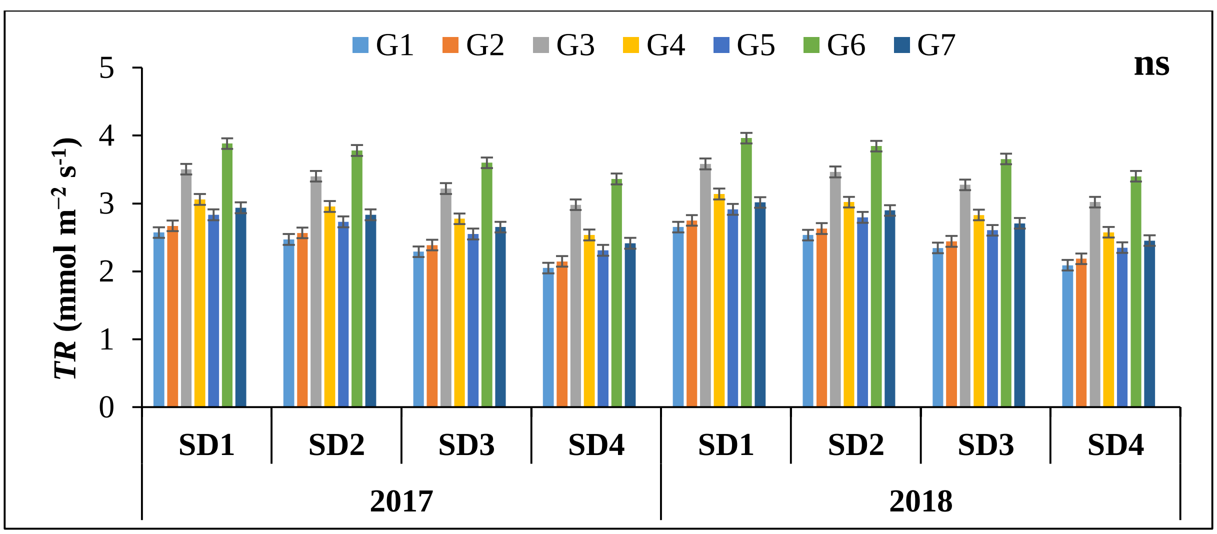

Fig 2: Effect of different sowing times and genotypes on transpiration rate (*TR*) in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

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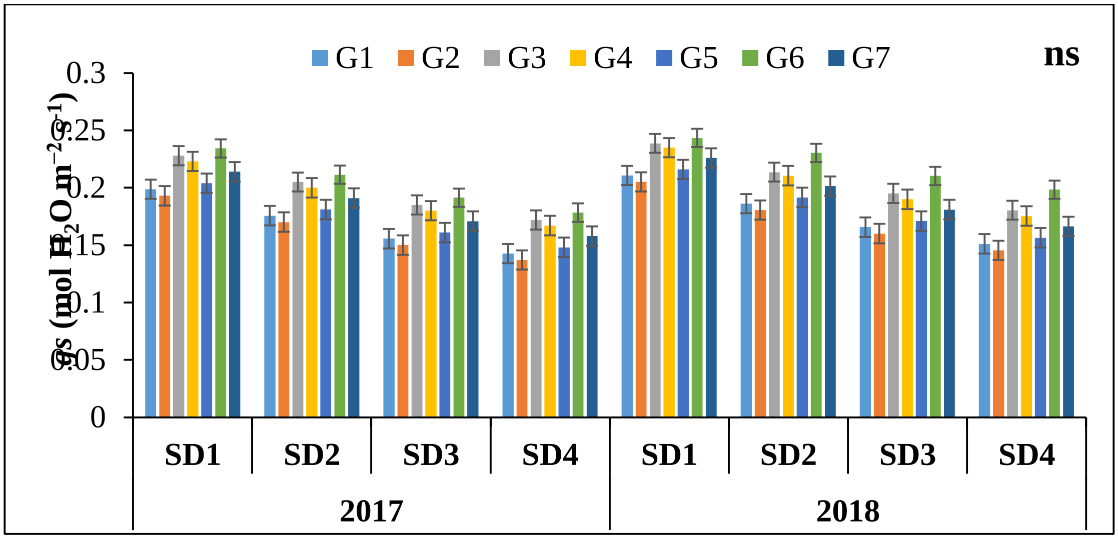

Fig 3: Effect of different sowing times and genotypes on stomatal conductance (*gs*) in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

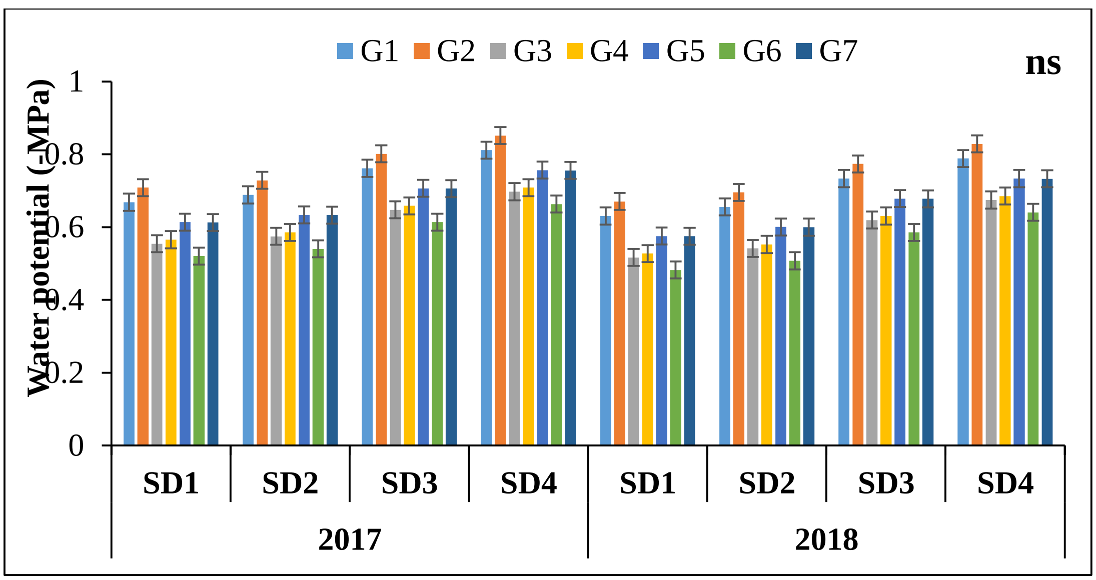

Fig 4: Effect of different sowing times and genotypes on water potential in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

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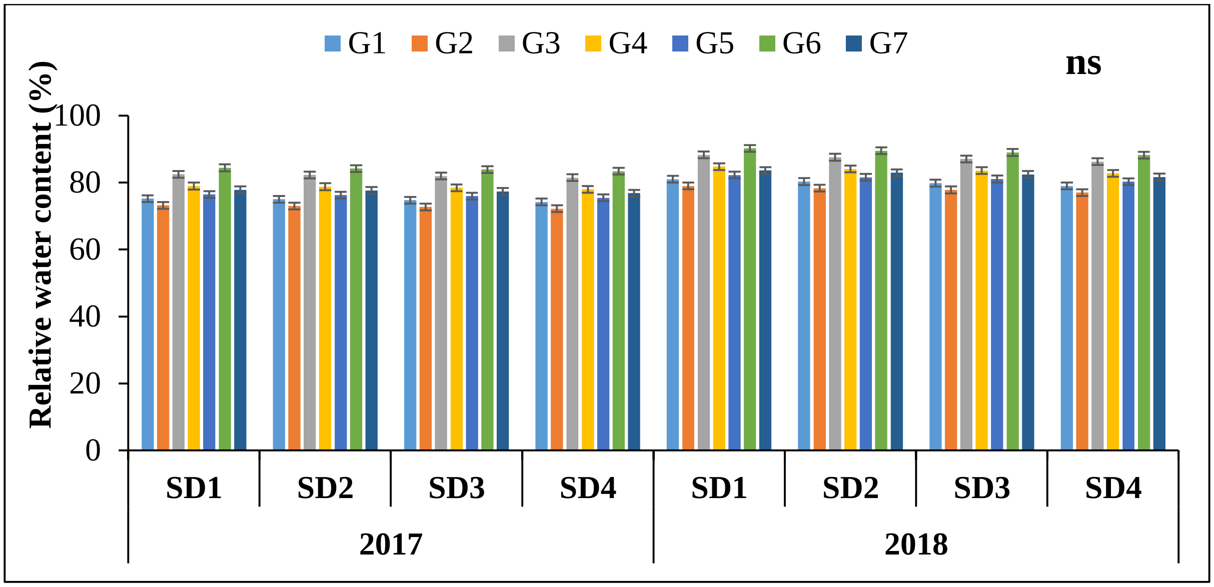

Fig 5: Effect of different sowing times and genotypes on relative water content in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

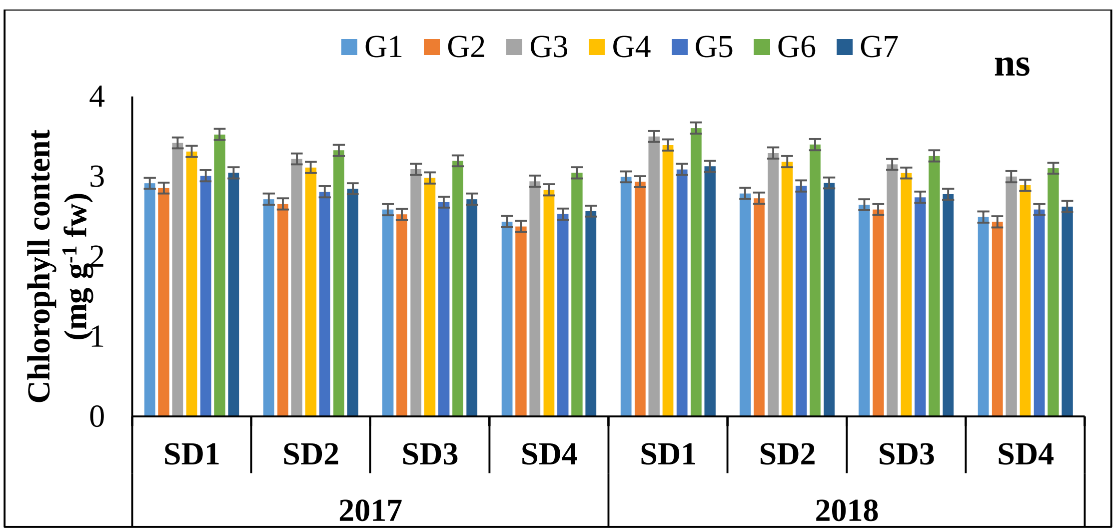

Fig 6: Effect of different sowing times and genotypes on chlorophyll content in soybean.

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal,

G6= Malakand-96. G7= Sawat-84. PN=Photosynthetic rate.

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Yield parameters

Sowing time and soybean genotypes significantly (*P < 0.05*) affected the seed yield and yield-related attributes, including the number of pods per plant, number of seeds per plant, 1000-seed weight, seed yield, and biological yield (Table 5). Analysis variance showed that soybean genotypes showed a significant variation in the number of pods per plant, number of seeds per plant, 1000-seed weight, seed yield, and biological yield measured in genotypes. Among the genotypes, maximum yield and yield-related attributes were measured in genotype-Malakand-96 which was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and minimum yield and yield attributes were measured in soybean genotype NARC-16, respectively.

Table 5: Effect of different sowing times on the seed yield, yield-related parameters, and seed quality parameters in soybean genotypes

Treatments		**Number of branches per plant**		**Number of pods per plant**		**Number of seeds per pod**		**Seed weight (g)**		**Seed yield**		**Seed oil content (%)**		**Seed protein content (%)**	
		2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Sowing times	**SD1**	7.95a	7.85a	34.3a	35.8a	2.09a	2.19a	104.5a	108.3a	1284.2a	1350.5a	19.8a	20.3a	37.5c	38.6c
	SD2	7.28b	7.42ab	32.2b	33.0b	2.00b	2.04ab	100.0b	103.8b	1249.4b	1315.2b	19.5b	18.9b	38.2bc	39.4b
	SD3	6.90c	7.19bc	30.4c	32.5bc	1.90bc	1.85ab	99.2b	101.8bc	1204.0c	1288.5bc	19.1c	18.5c	38. 8ab	39.8b
	SD4	6.28d	6.85c	29.2c	31.1c	1.88c	1.80b	96.4c	99.5c	1173.3c	1262.0c	18.6d	18.3c	39.4a	40.4a
LSD (*P < 0.05*)		**0.36**	**0.43**	**1.46**	**1.57**	**0.08**	**0.18**	**2.02**	**2.65**	**33.6**	**31.8**	**0.32**	**0.26**	**0.66**	**0.36**
Genotypes	**G1**	6.08c	6.50c	24.4d	24.7e	1.66e	1.50de	91.8e	93.5e	1061.3d	1144.2e	18.3de	18.4d	38.9ab	40.5b
	G2	5.91c	6.50c	18.0e	22.0f	1.51f	1.41e	89.9e	94.3e	1006.0e	1062.8f	18.1e	18.0e	39.7a	41.6a
	G3	7.33b	8.41b	45.7a	48.2b	2.25b	2.41ab	106.7b	108.5b	1436.3b	1576.2b	20.5a	19.7b	37.8c	38.9c
	G4	7.25b	7.00c	29.5b	30.4c	2.08c	2.08bc	102.7c	100.3d	1208.9c	1313.9c	19.7b	19.2c	38.0bc	39.0c
	G5	7.08b	6.58c	27.0c	27.1d	1.88d	1.66cde	98.1d	102.5 cd	1104.0d	1185.6de	18.6cd	18.4de	39.4a	40.3b
	G6	8.66a	9.41a	46.5a	50.4a	2.50a	2.75a	109.8a	118.8a	1570.0a	1637.2a	20.7a	20.6a	36.5d	37.4d
	G7	7.41b	6.91c	29.5b	29.0cd	2.00cd	2.00bcd	101.2c	105.6bc	1207.6c	1208.4d	19.1c	18.7d	39.1a	39.2c
LSD (*P < 0.05*)		**0.47**	**0.57**	**1.94**	**2.08**	**0.12**	**0.50**	**2.68**	**3.51**	**44.5**	**42.1**	**0.43**	**0.35**	**0.87**	**0.47**

SD1= 6th July, SD2= 21st July, SD3= 4 August, and SD4= 19 August; G1= NARC-2, G2= NARC-16, G3= Faisal Soy, G4= Ajmeri, G5= Rawal, G6= Malakand-96. G7= Sawat-84. LSD= Least significant difference; Values sharing the same case letter or without lettering, for a parameter, do not differ significantly ($P \leq 0.05$) by the LSD test.

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Among the sowing times, sowing time-6th July showed maximum yield and yield-related attributes followed by 21st July, 4 August, and 19 August, respectively. The interactions among soybean genotypes and sowing times were significant for all the yield parameters. In addition, soybean genotypes have shown better seed yield and yield-related attributes in the year 2017 as compared to 2018.

Seed quality parameters

Sowing time and soybean genotypes significantly ($P<0.05$) affected the seed quality attributes, including seed protein content and seed oil content. However, the relation between seed oil and seed protein contents was found inverse to each other. Analysis variance showed that soybean genotypes showed a significant variation in the seed quality parameters as maximum seed oil content was measured in genotype-Malakand-96 which was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and minimum seed oil content was measured in soybean genotype NARC-16, respectively. However, maximum seed protein content was observed in soybean genotype NARC-16 and minimum seed protein was observed in Malakand-96. Among the sowing times, sowing time-6th July showed maximum seed oil content and minimum seed protein content. The interactions among soybean genotypes and sowing times were significant for all the yield quality parameters. In addition, soybean genotypes showed better oil content in the year 2017 as compared to 2018. However, the year 2018 showed more protein content as compared to the year 2017.

DISCUSSION

The findings demonstrated a substantial relationship between sowing time and soybean genotypes' plant physiology, seed yield, and yield quality. Summer crops harvested late, for various reasons, are subject to high temperatures and low moisture content. The two years of varied climatic circumstances (air temperature and rainfall) might be used to explain the differences in the examined features; in particular, the exposure to high temperatures during the later stages of the crop and delayed sowing can be a contributing factor. The first year (2017) had a higher mean air temperature and less rainfall than the second year (2018), which had an adverse influence on the growth, seed yield, and seed quality of soybean plants. It was also noted how distinct genotypes may differ genetically. The soybean genotype Malakand-96 outperformed other genotypes in terms of yield qualities and plant growth, according to the results. On the other hand, the tendency was noted for Faisal Soy, Ajmeri, Sawat-84, Rawal, NARC-2, and NARC-16, in that order, from higher to lower. Results have revealed that plant phenological attributes including days to 50% emergence, days to flowering, days to pod development, days to maturity, and plant height were significantly affected by the different sowing times as sowing times correspond according to the environmental conditions and moisture availability (Yang *et al*., 2021). Among the seeding dates, July 6th performed the best since the plant had superior growing conditions and a longer growing season. As a function of crop genetics and management, we demonstrated that sowing time has important ramifications for

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phenology, in line with earlier research (Phelan *et al*., 2018, Liu *et al*., 2021, Zheng *et al*., 2024). In many farming systems, modifying the sowing period has become a common practice as a means of adapting to climate change (Zhang *et al*., 2022, Li *et al*., 2022, Muleke *et al*., 2022). According to our findings, vegetative growth length was often shorter when seeding later. This could be because a greater minimum temperature encouraged phenology and growth (Guo *et al*., 2023). Furthermore, our findings demonstrate that the length of the vegetative stage was considerably shortened under late sowings due to the rising minimum temperature. On the other hand, in keeping with previous research, very late seeding resulted in cooler weather later in the growing season, which shortened the reproductive stage (Zhu *et al*., 2022). According to our findings, vegetative growth length was often shorter when seeding later. This could be because a greater minimum temperature encouraged phenology and growth (Guo *et al*., 2023). Furthermore, our findings demonstrate that the length of the vegetative stage was considerably shortened under late sowings due to the rising minimum temperature. On the other hand, in keeping with previous research, very late seeding resulted in cooler weather later in the growing season, which shortened the reproductive stage (Guo *et al*., 2022). For growers, the most important agronomic practices that may impact crop yield and yield quality are sowing time in conjunction with crop genotypes and environmental conditions. These variables include the duration of the calendar year, temperature fluctuations during minor phenological occurrences and the accumulation of heat units from sowing to physiological maturity (Ghamkhar *et al*., 2010; Neupane *et al*., 2019). Days to flowering are an important factor in the initiation of the reproductive stage of soybean which contributes to grain formation and ultimately final yield. The results regarding phenological attributes obtained in this study are in support of the findings of Dadson (1976), who evaluated different soybean cultivars and found that most of them flowered at the optimal date, around 35-50 days after sowing. The disparity in results could be attributed to differences in the genetic makeup of the breeding materials used and the prevailing environmental conditions. Another major reason is the classification of germplasm in different maturity groups which is yet to be documented in the country (Asad *et al*., 2020). Because it directly affects the characteristics of gas exchange, the water status of plants is essential to their healthy growth and development (Ahmad *et al*., 2023 a, b). Leaf water status decline is one of the most significant and fundamental impacts of drought stress. When soybean plants are under adverse conditions, their leaf water potential can also significantly decrease due to water stress (Khatun *et al*., 2021). Due to high temperatures and little rainfall, later sowing times revealed lower plant hydration status than early planted crops, with a greater loss seen in 2018 compared to 2017. The relative water content (RWC) and osmotic potential of plants both sharply decrease at high temperatures (Chand *et al*., 2020). Consistent with the results of this study, late-planted crops under adverse conditions exhibit a decrease in photosynthetic rate, stomatal conductance, transpiration rate, osmotic potential, and relative water content, regardless of the cultivars examined (de Castro *et al*., 2019). In comparison to early-sown crops, late-sown crops exhibited a notable decrease in plant chlorophyll content, which enhanced the growth and development of the former. Since heat stress and drought

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directly affect plants' photosynthetic machinery, chlorophyll parameters including content, fluorescence and stability index are thought to be essential characteristics for determining a genotype's resistance to these environmental stresses. Higher levels of chlorophyll indicate a plant's capacity to tolerate stress because they increase the integrity of the chloroplast membranes, which promotes increased rates of photosynthesis, the generation of dry matter, and higher productivity (Nahakpam, 2017). The combination of high temperatures in July and August, strong wind speeds, and low relative humidity intensifies water stress, which could potentially decrease the concentration of enzymes involved in the synthesis of chlorophyll (Ahmad *et al*., 2023 d). The amount of water available for irrigation is becoming less and more expensive due to the introduction of other irrigated crops to these locations, recurring droughts, and competing demands (such as the environment) for the limited amount of water. Determining the ideal sowing time requires an understanding of how soybean production responds to various sowing dates. Soybean production in the tight winter-summer crop cycle can only be practical if commercially viable yields are obtained, even if the sowing date is postponed (Zeleke and McCormick, 2022). Days to pod formation are involved in the growth and development of soybeans. The range observed for the number of days to reach pod formation and maturity in this study varied from 45-70 and 91 to 109 days respectively. A perfect time to seed crops is necessary for best output. However, farmers' capacity to sow on time is frequently limited by weather and the schedule of farming operations (Colet *et al*., 2023). Reduced photosynthetic pigmentation (PN) eventually inhibits crop growth and development and may result in leaf senescence from chlorophyll breakdown (Noctor *et al*., 2018). A perfect time to seed crops is necessary for best output. However, farmers' capacity to sow on time is frequently limited by weather and the schedule of farming operations (Colet *et al*., 2023). Reduced photosynthetic pigmentation (PN) eventually inhibits crop growth and development and may result in leaf senescence from chlorophyll breakdown (Noctor *et al*., 2018). When late-seeded soybeans are sown, they are exposed to high temperatures that cause photosynthetic pigments to break down (Noctor *et al*., 2018). This can have an effect on the leaf water status of the soybeans in both years (Carmo-Silva and Salvucci, 2012; Lindsey *et al*., 2016). According to earlier research, heat stress around blooming can prevent assimilation products from being synthesized and transported, which lowers yields (Thomey *et al*., 2019). This may be explained by heat stress creating a greater vapor pressure deficit and a greater discrepancy between crop demand and soil water availability (Ibrahim *et al*., 2019). This may result in leaves having a higher CO_2 content, which would produce more reactive oxygen species (ROS) and decrease cellular activity (Zhou *et al*., 2017). Choosing a suitable planting date might therefore lessen the negative effects of heat stress on soybean output; nevertheless, heat stress must be weighed against other meteorological, cultivar, and management factors (do Rio *et al*., 2016, Ibrahim *et al*., 2019). The data regarding yield and yield components revealed that genotype Malakand-96 showed maximum yield and yield-related attributes as it counted maximum growing degree days which led to the proper growth and development and ultimately seed yield. However, Malakand-96 showed a maximum number of seeds, thousand seed weight, and seed yield by showing its superior genetic

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potential which was followed by Faisal soy, Ajmeri, Sawat-84, Rawal, NARC-2, and minimum yield and yield attributes were measured in soybean genotype NARC-16 due to its weaker genetic potential. This may be due to the effect of climatic conditions and soil properties. Khan *et al*., (2015) also reported significant differences among branches per plant of soybean genotypes. The low yield of soybeans in the present study suggested the effect of genetic material, soil, and environmental factors as an increase in temperature affected the yield stability in soybeans.

CONCLUSION

In conclusion, the phenological, morphological, and physiological characteristics of soybean were greatly impacted by sowing times and genotypic variabilities; the detrimental effects were greater when the soybeans were exposed to high temperatures and low moisture content. However, the presence of genotypic variants can be more effectively employed, since soybeans only react physiologically to a combo of stimuli. This facilitates the discovery and utilization of possible genotypes and cultivars in the germplasm that show multiple stress resistance to a wide variety of abiotic stressors.

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