# Optimising the resilience of wheat to a changing climate in North Kashmir, India

**S. Sheraz Mahdi[1,*], Rukhsana Jan[1], Owais Ali Wani[2], Alexandre S. Gagnon[3], M. Anwar Bhat[1], F. A. Bahar[1], Reyazul Rouf Mir[4], Bhagyashree S. Dhekale[5], S. A. Bangroo[2] and Raies Ahmed Bhat[1]**

[1]Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar 190 025, India
[2]Division of Soil Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar 190 025, India
[3]School of Biological and Environmental Sciences, Liverpool John Moores University, Liverpool L3 3AF, United Kingdom
[4]Division of Genetics and Plant Breeding, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar 190 025, India
[5]Division of Agriculture Statistics, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar 190 025, India

**Three field experiments were conducted to assess the performance of various spring wheat genotypes, viz., SKAU-101 ($V_1$), SKAU-102 ($V_2$) and Shalimar Wheat-2 ($V_3$). These genotypes were sown on different dates: 15 October ($S_1$), 1 November ($S_2$) and 15 November ($S_3$) during the 2020–2021 winter (*rabi*) season. Randomised complete block design (RCBD) was employed for the experimental setup in North Kashmir, India. This design facilitated a thorough examination of each genotype's response to the different planting dates within the specified agroecological context. The crops sown on 15 October showed superior growth, phenology and yield (4.01 t ha$^{-1}$ for grain). The SKAU-102 variety required less time to reach various phenological stages, matured 5–12 days earlier than the other two genotypes, and produced a higher yield; the highest yield (4.4 t ha$^{-1}$) was observed with the SKAU-102 genotype when sown early ($V_2S_1$). Furthermore, climate change trends in the region from 1980 to 2021 revealed statistically significant increases in maximum and minimum temperatures at a rate of 0.02°C per year, accompanied by a decreasing trend in precipitation at a rate of -4.53 mm per year, which, if they continue, can adversely affect wheat growth, development and yield. Considering the ongoing climate changes and the findings from field experiments, it is advisable to sow the wheat genotype SKAU-102 by 15 October to achieve the earliest maturity and the highest yield, in contrast to the typical sowing date of mid-November in the region.**

**Keywords:** Climate change, India, North Kashmir, phenology, sowing window, wheat.

WHEAT (*Triticum aestivum* L.) is a dual-purpose crop yielding grain and fodder. It is the most extensively cultivated crop worldwide, covering an area of 219 million ha[1]. With over three billion people relying on wheat for sustenance in various forms[2], it is a highly adaptable crop, capable of thriving in diverse soil and climatic conditions[3,4]. In India, wheat cultivation spans 31.6 million hectares, yielding an average annual production of nearly 110 million tons, corresponding to approximately 3.48 t ha$^{-1}$. While predominantly cultivated in the plains, wheat also finds its place in the mountainous regions of North India, being grown on hills[6].

As temperatures continue to rise due to climate change, the agricultural sector in India faces a significant threat, particularly regarding wheat production and national food security. Studies project that for every one-degree Celsius increase in temperature, wheat production in India could decrease by four to six million tons[7,8]. Despite this challenge, the national government aims to gradually increase wheat production to 140 million tons annually by 2050 (ref. 9). Achieving this target would necessitate a rise in productivity from 3.48 t ha$^{-1}$ to 4.43 t ha$^{-1}$, assuming the surface area available for wheat cultivation remains unchanged[10].

In the state of Jammu and Kashmir in North India, wheat is cultivated in 244,000 ha with an average yield of 1.98 t ha$^{-1}$ (ref. 11), which is very low compared to the national average. Moreover, wheat cultivation is primarily confined to the Jammu region, of which only 1,300 ha are in the Kashmir Valley. The usual planting time for wheat cultivation in Kashmir is the first fortnight of November. Although Kashmir's climate is temperate and suitable for wheat cultivation, its acreage has remained low due to the long cultivation period (approximately 245 to 250 days). This duration does not allow sufficient time for a rice crop, the preferred crop in the region, to be planted and harvested on the same land. Therefore, efforts are needed to identify and develop wheat genotypes that mature more quickly (preferably by the end of May)

*For correspondence. (e-mail: syedapbau@skuastkashmir.ac.in)

to allow rice transplanting in the first week of June without compromising the overall yield. This would allow for a wheat-rice rotation system in the region, as is common in many parts of South Asia. Various abiotic and biotic factors, including unpredictable weather patterns, inadequate high-yielding genotypes, and the underperformance of current cropping systems and available technologies, can negatively impact wheat productivity[12,13]. In the temperate climatic conditions of Kashmir, selecting the correct sowing dates is crucial for successful wheat production. The choice of wheat variety is also important as different genotypes respond differently to climate, sowing time, fertiliser application, crop geometry and irrigation scheduling[14,15]. The trends towards warmer temperatures observed in the past few decades in many regions of India[16,17] have caused considerable changes in the yield of cereal crops and their phenology[18]. With temperatures likely to rise in the coming years and decades, research has found that a decrease in wheat crop yield is expected in many countries worldwide, notably Iran, Russia, Egypt and India[19–21].

Assessing the impacts of climate change on crop phenology is complex due to its susceptibility to various factors that influence it. Changes in crop management, such as adjusting sowing timing, using different crop varieties and modifying fertiliser application, can help mitigate some of these impacts[22]. Therefore, altering sowing dates and crop varieties could be beneficial adaptations to climate change[23].

The objectives of this study are (i) to assess recent climate change patterns in the Kashmir Valley and (ii) to evaluate the influence of altered sowing dates and wheat genotypes on the development, phenology, and yield of wheat in the region. The aim is to recommend the most suitable sowing dates and cultivars to enhance wheat resilience to climate change.

## Materials and methods

### *Description of the study area*

Field investigations were conducted at the Agronomic Research Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Srinagar (Figure 1), during the winter (*rabi*) seasons of 2019–2021. The study site is in the extreme northern part of Jammu and Kashmir, at an elevation of 1690 m above sea level. Daily weather data were obtained from a weather station installed at the Agronomic Research Farm. The data collected during the crop growth periods from October 2019 to June 2020 and October 2020 to June 2021 show that the maximum temperatures were 16.82°C and 18.07°C, while the minimum temperatures were 3.05°C and 2.9°C respectively. The total precipitation recorded during these periods was 1159.1 mm and 878.0 mm respectively (Figure 2). The soil type at the experimental site was clay-loam in texture. A sample up to a depth of 20 cm was analysed, and its soil properties are shown in Table 1.

### *Experimental design*

The field experiment employed a randomised complete block design (RCBD) on a plot size of 17.83 $m^2$, with two factors: a change in crop variety and a shift in sowing dates, replicated three times. The treatments consisted of three sowing dates, namely 15 October ($S_1$), 1 November ($S_2$) and 15 November ($S_3$), and three spring wheat genotypes: SKAU-101 ($V_1$), SKAU-102 ($V_2$) and Shalimar Wheat-2 ($V_3$). A seed rate of 80 kg $ha^{-1}$ and the application of 120 kg N, 80 kg $P_2O_5$, 60 kg $K_2O$ and 20 kg $ZnSO_4$, as recommended by SKUAST-K, were utilised during the experimentation. Seeds were sown manually in furrows, keeping 23 cm between the rows and maintaining a seed depth of 5–6 cm to ensure proper germination.

### *Measurements and analytical techniques*

From ten randomly selected plants from each plot, the plant height was measured from the base of the tillers to the tip of the longest leaf initially and after ear emergence from the tiller's base to the apex of the tallest tiller. The leaf area index (LAI) was measured at various phenological stages using a canopy interception and LAI Analyser (METER ACCUPAR LP-80). The number of days required to reach different phenological stages, i.e., crown root initiation, active tillering, booting, flowering, milking, dough and physiological maturity, was identified when more than 50% of the plants in each plot reached that stage. The yield components, i.e., spike number, grains per spike and 1,000-grain weight, in each plot were recorded at maturity. Wheat plants were harvested from each square meter area for grain and straw yield, and the harvest index (HI), the ratio of grain yield (also referred to as the economic yield) to the total above-ground biomass, was obtained using the following formula:

$$HI(\%) = \frac{Economic\ yeild\ (gain)}{straw\ yield + gain\ yeild} \times 100$$

### *Data processing and statistical analysis*

Data were analysed using SAS 9.0 (ref. 24). The least significant difference (LSD) tests were used to compare the treatment means.

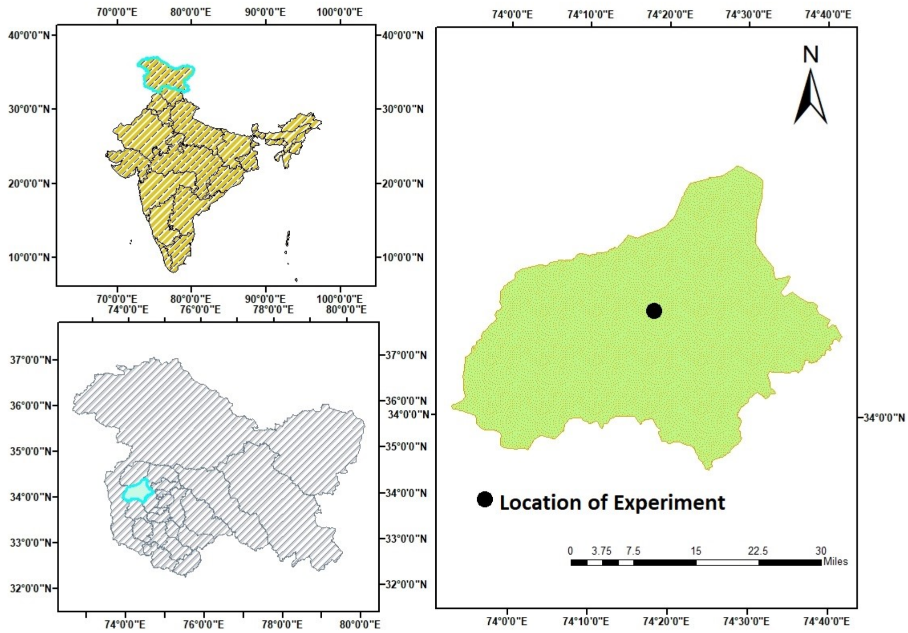


**Figure 1.** The location of the experimental site at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar.

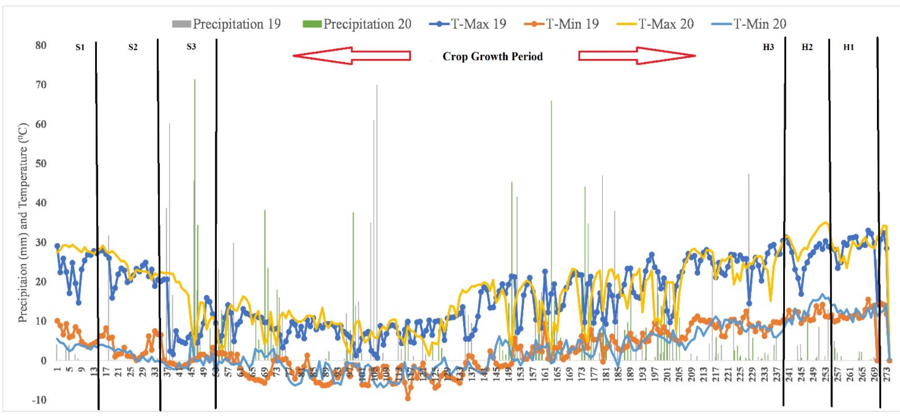


**Figure 2.** Mean daily weather data from October 2019–June 2020 and October 2020–June 2021 (S1, S2 and S3 indicate sowing dates, while H1, H2 and H3 indicate crop harvesting dates).

**Table 1.** Soil properties of the experimental site

| Property | Value |
|---|---|
| pH | 7.6 |
| Organic carbon (%) | 0.9 |
| Electrical conductivity (dS/m) | 0.12 |
| Available N (kg ha$^{-1}$) | 315.4 |
| Available P (kg ha$^{-1}$) | 21.5 |
| Available K (kg ha$^{-1}$) | 248.77 |

## *Trends in climate variables*

Maximum and minimum temperature and precipitation data for 1980–2021 were obtained from the Indian Meteorological Department, Kashmir. The presence of annual trends in the time series was tested using linear regression and the non-parametric Mann-Kendall (MK) test. Before testing for trends, the time series were subjected

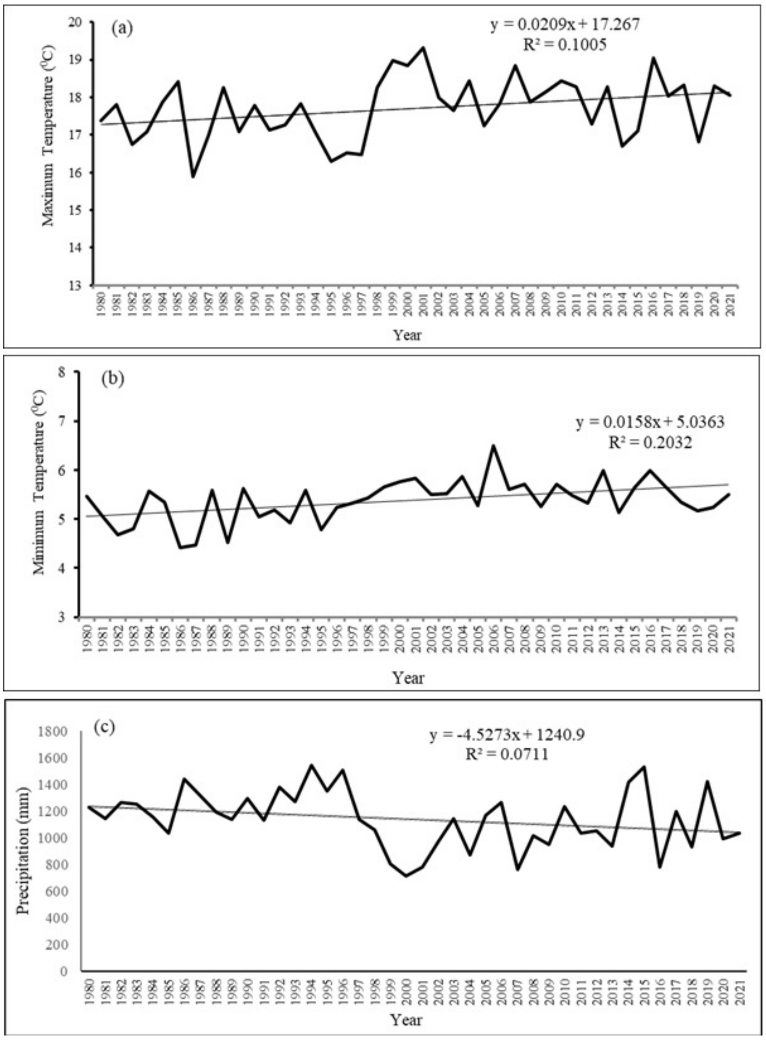


**Figure 3.** Annual trends in the maximum (***a***) and minimum temperatures (***b***) and precipitation (***c***) at a weather station in the Kashmir Valley during the period 1980–2021.

**Table 2.** The effect of sowing dates and genotypes on plant height (cm) at different crop growth stages of wheat for 2020 and 2021

| Treatment | Active tillering stage | Jointing stage | Booting stage | Flowering stage | Milking stage | Dough stage | Physiological maturity (days) |
|---|---|---|---|---|---|---|---|
| *Sowing dates* | | | | | | | |
| 15 October ($S_1$) | 22.67 | 58.93 | 90.26 | 95.94 | 100.93 | 101.66 | 101.69 |
| 1 November ($S_2$) | 21.04 | 57.35 | 85.94 | 92.89 | 98.09 | 98.71 | 98.76 |
| 15 November ($S_3$) | 20.12 | 54.97 | 83.75 | 90.11 | 95.61 | 97.13 | 97.15 |
| SEm± | 0.20 | 0.35 | 0.38 | 0.32 | 0.29 | 0.48 | 0.50 |
| CD ($p \leq 0.05$) | 0.62 | 1.05 | 1.15 | 0.99 | 0.89 | 1.47 | 1.52 |
| *Genotypes* | | | | | | | |
| SKAU-101 ($V_1$) | 19.73 | 53.32 | 80.16 | 89.16 | 92.32 | 93.98 | 94.01 |
| SKAU-102 ($V_2$) | 22.30 | 59.89 | 91.26 | 97.71 | 103.03 | 103.59 | 103.63 |
| Shalimar Wheat-2 ($V_3$) | 21.79 | 58.04 | 88.52 | 92.08 | 99.28 | 99.92 | 99.97 |
| SEm± | 0.20 | 0.35 | 0.38 | 0.32 | 0.29 | 0.48 | 0.50 |
| CD($p \leq 0.05$) | 0.62 | 1.05 | 1.15 | 0.99 | 0.89 | 1.47 | 1.52 |

to a standard normal homogeneity test to ensure that the assumption of linear regression was met[25]. Likewise, the time series were tested for serial correlation, which could invalidate the MK test results[26].

**Table 3.** The effect of sowing dates and genotypes on leaf area index for different growth stages of wheat during 2020 and 2021

| Treatments | Active tillering stage | Jointing stage | Booting stage | Flowering stage | Milking stage | Dough stage | Physiological maturity |
|---|---|---|---|---|---|---|---|
| Sowing dates | | | | | | | |
| 15 October ($S_1$) | 1.67 | 2.90 | 3.64 | 3.97 | 3.62 | 2.94 | 2.91 |
| 1 November ($S_2$) | 1.64 | 2.42 | 3.52 | 3.83 | 3.48 | 2.79 | 2.76 |
| 15 November ($S_3$) | 1.60 | 2.30 | 3.40 | 3.72 | 3.29 | 2.63 | 2.59 |
| SEm± | 0.01 | 0.07 | 0.01 | 0.007 | 0.02 | 0.01 | 0.01 |
| CD ($p \leq 0.05$) | 0.03 | 0.21 | 0.05 | 0.022 | 0.05 | 0.04 | 0.04 |
| Genotypes | | | | | | | |
| SKAU-101 ($V_1$) | 1.61 | 2.24 | 3.38 | 3.70 | 3.32 | 2.62 | 2.60 |
| SKAU-102 ($V_2$) | 1.67 | 2.88 | 3.65 | 3.99 | 3.61 | 2.89 | 2.86 |
| Shalimar Wheat-2 ($V_3$) | 1.63 | 2.50 | 3.53 | 3.83 | 3.47 | 2.84 | 2.81 |
| SEm± | 0.01 | 0.07 | 0.01 | 0.007 | 0.02 | 0.01 | 0.01 |
| CD ($p \leq 0.05$) | 0.03 | 0.21 | 0.05 | 0.022 | 0.05 | 0.04 | 0.04 |

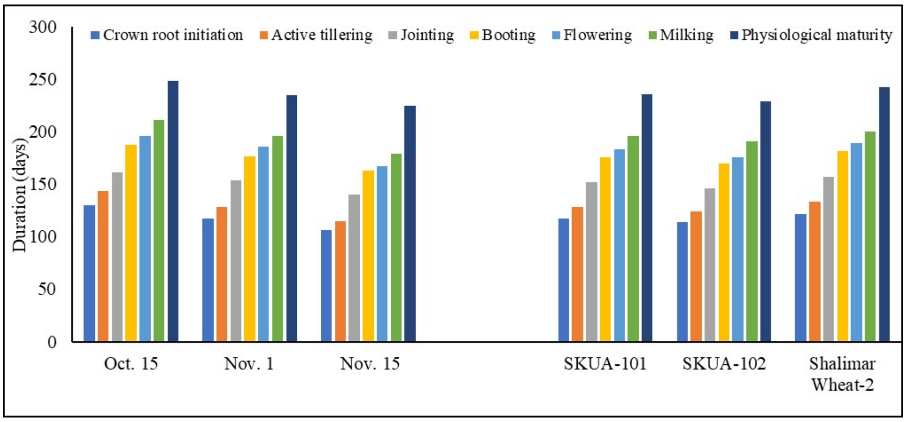


**Figure 4.** The effect of sowing dates and genotypes on different phenological stages of wheat during 2020 and 2021.

**Table 4.** Effect of sowing dates and genotypes on wheat grain, straw yield and harvest index for 2020 and 2021

| Treatments | Grain yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) | Harvest index (%) |
|---|---|---|---|
| Sowing dates | | | |
| 15 October ($S_1$) | 4.01 | 7.54 | 34.65 |
| 1 November ($S_2$) | 3.57 | 7.04 | 33.57 |
| 15 November ($S_3$) | 2.73 | 6.28 | 30.30 |
| SEm± | 0.05 | 0.01 | 0.35 |
| CD ($p \leq 0.05$) | 0.18 | 0.04 | 1.07 |
| Genotype | | | |
| SKAU-101 ($V_1$) | 3.05 | 6.40 | 30.20 |
| SKAU-102 ($V_2$) | 3.77 | 7.50 | 33.23 |
| Shalimar Wheat-2 ($V_3$) | 3.48 | 6.97 | 31.09 |
| SEm± | 0.05 | 0.01 | 0.29 |
| CD ($p \leq 0.05$) | 0.18 | 0.04 | 0.93 |

## Result and discussion

### *Climate change in Kashmir Valley*

*Trends in maximum and minimum temperatures:* The MK test identified statistically significant trends in mean annual maximum and minimum temperature over the Kashmir Valley, increasing at approximately 0.02°C/year from 1980–2021 (Figure 3 *a*–*b*). It also revealed a step change in 1997 ($p$-value = 0.01) in yearly maximum temperature, with the maximum temperature, on average, being higher in the more recent decades (1997–2021) compared to previous decades (1980–1996). A step change in the yearly minimum temperature was also detected in 1996, with warmer temperatures experienced after 1996 compared to those in previous decades.

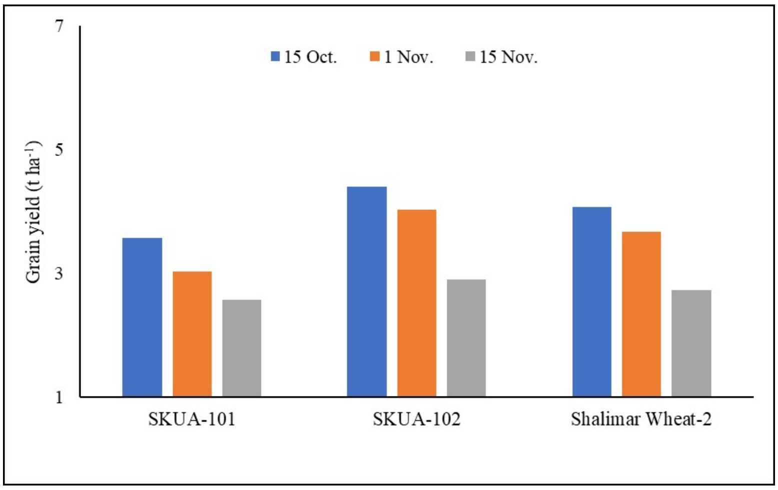


**Figure 5.** The interaction effect of sowing dates and genotypes on wheat grain yield during 2020 and 2021.

*Trends in precipitation:* A decreasing trend in total annual precipitation of -4.53 mm/year was detected over Kashmir Valley for 1980–2021 (Figure 3 *c*). Seasonally, a statistically significant decreasing trend of -4.72 mm/year in spring precipitation was identified. This has implications for the region's water resources, as glacier melt is the primary source of irrigation water in the region.

*Effect of sowing date and genotype on growth and development of wheat:* Different sowing dates and wheat genotypes can lead to substantial variations in crop development. At various crop growth stages, plant height and LAI were significantly higher in the case of the early-sown crops compared to mid and late-sown ones (Tables 2 and 3). Increases in plant height are continuous throughout the crop growth cycle. Still, as expected, the LAI increases up to the flowering stage, after which it decreases until the crop reaches maturity. Environmental conditions and the cultivar's genetic makeup influence crop height and LAI. Among the genotypes investigated, SKAU-102 reached the maximum plant height and LAI at all crop growth stages.

Decreased growth indices (plant height, LAI) in a late-sown crop might be correlated with a shorter growth period due to warmer temperatures in late spring (Figure 2). This reduces photosynthesis activity, carbohydrate translocation and assimilation, causing the crop to flower and mature earlier[27]. Late sowing after the suggested date may also prevent wheat from achieving its full genetic yield potential[22].

*Effect of sowing date and genotypes on the phenology of wheat:* Figure 4 shows the impact of sowing date and wheat genotype on the duration of different growth stages. Sowing wheat by mid-October results in prolonged periods for crown root initiation, active tillering, booting, anthesis and maturity compared to sowing in early to mid-November. Deng *et al.*[28] also noted a reduction of four days in wheat's overall growth and phenology period when the sowing date was delayed by just five days.

Among the three genotypes, SKAU-102 booted, flowered, and reached maturity earlier than SKAU-101 and Shalimar Wheat-2 in 2020 and 2021 (Figure 4). These results suggest that the SKAU-102 genotype outperforms the locally adapted variety (Shalimar Wheat-2), reaching maturity 5 and 12 days earlier than SKAU-101 and Shalimar Wheat-2. This could be due to the different warmth requirements of varieties to complete their life cycle[29].

*Effect of sowing date and genotypes on wheat yield:* Table 4 shows that crops sown early produce higher yields of grain and straw, resulting in a higher HI than those sown in early and mid-November. The average grain yield of early-sown wheat in 2020 and 2021 was 12% and 47% higher than in early and mid-November respectively. The decrease in wheat yield observed when sown in November is likely due to environmental factors such as low temperatures during the crop's emergence and vegetative growth, shortened duration of various crop growth stages, and higher temperatures during grain filling[30,31].

SKAU-102 yielded more grain and straw and had a higher HI than the other two genotypes. The pooled grain yield of SKAU-102 was 8.28% and 23.63% higher than that of Shalimar Wheat-2 and SKAU-101 respectively, while the pooled straw yield was 7.60% and 17.18% higher than that of Shalimar Wheat-2 and SKAU-101 respectively. Such variation in yield in different genotypes could be due to the genetic makeup of a variety[30].

*Interaction effect :* The highest grain yield (4.4 t $ha^{-1}$) was obtained from the interaction between genotype

SKAU-102 and the sowing date of 15 October ($V_2S_1$), followed by Shalimar Wheat-2 ($V_3S_1$) and SKAU-101 ($V_1S_1$) for the same sowing date (Figure 5). The lowest grain yield (2.56 t $ha^{-1}$) was recorded from the interaction of genotype SKAU-101 and the sowing date of 15 November (V1S3). Rahman *et al.*[32] also reported a significant decline in the yield of the Shatabdi wheat variety when sowing late (10 December) compared to early sowing (20 November). The higher yield can be attributed to the optimal crop growth period enabled by early sowing and the genetic potential of genotype SKAU-102.

## Conclusion

The impact of climatic variations on wheat growth and yield necessitates implementing adaptive measures, such as adjustments in crop management techniques and cultivating diverse wheat genotypes. These considerations are crucial for preserving and enhancing crop yield in evolving climatic conditions. A decrease in precipitation and warming trends in minimum and maximum temperatures were detected across the Kashmir Valley. The present study examined the response of three widespread wheat genotypes to different sowing dates in Kashmir, India, during the winters of 2020 and 2021, in terms of growth, phenology and yield. The results show that wheat genotype SKAU-102, when sown early (15 October), attained physiological maturity earlier for all crop growth stages and recorded a higher grain yield than the other genotypes sown later. SKAU-102 was also sown during the other two dates, as in the case of the other varieties. For this reason, if this genotype were to be sown by mid-October, it could be harvested before the high spring temperatures that cause stress and damage to crops. Early maturity of this wheat genotype may also allow a wheat-rice rotation within a calendar year in the region, with further research recommended on the latter.

The Kashmir Valley predominantly relies on a rice-based cropping system during the summer (*kharif*) due to favourable climatic conditions, including sufficient water and a lengthy growing season suitable for rice, a long-duration crop. In contrast, wheat is typically cultivated as a winter (*rabi*) crop in the region. However, in North Kashmir, the current climatic conditions do not allow harvesting wheat before rice is planted, posing a challenge to implementing a wheat-rice cropping system, a widely practised agricultural system in many parts of India. If climate change results in warmer temperatures in North Kashmir, it could create an opportunity for a wheat-rice rotation, allowing time to cultivate rice in the summer and wheat in the winter without one crop encroaching on the other's growing period.


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