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

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Short running title: Adjusting sowing window and choice of wheat cultivar

ABSTRACT

Three field experiments were conducted to assess the performance of various wheat genotypes, viz., SKAU-101 (V_1), SKAU-102(V_2), and Shalimar Wheat-2 (V_3). These genotypes were sown on different dates: October 15 (S_1), November 1 (S_2), and November 15 (S_3) during the 2020-2021 Rabi (winter) season. Randomized Completely 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 October 15 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 October 15 to achieve the earliest maturity and the highest yield, in contrast to the typical sowing date of mid-November in the region.

Keywords: Winter wheat, climate change, sowing window, phenology, yield, North Kashmir, India

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 ha¹. With over three billion people relying on wheat for sustenance in various forms², 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 hills⁶.

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 2050⁹. 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 unchanged¹⁰.

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 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 located 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) to allow for 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 phenology¹⁸. 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^{19,20,21}.

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 fertilizer application, can help mitigate some of these impacts²². Therefore, altering sowing dates and crop varieties could be beneficial adaptations to climate change²³.

The objectives of this study are to (i) assess recent climate change patterns in the Kashmir Valley and (ii) evaluate the influence of altered sowing dates and wheat genotypes on the development, phenology, and yield of winter wheat in the region. The aim is to recommend the most suitable sowing dates and cultivars to enhance winter 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, Wadura Campus (Figure 1), during the winter (Rabi) seasons of 2019-2021. The study site is in the extreme northern part of

Jammu and Kashmir, India, 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 Randomized Completely Block Design (RCBD) on a plot size of 17.83 m², 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 October 15 (S1), November 1 (S2), and November 15 (S3), and three wheat genotypes: SKAU-101 (V1), SKAU-102 (V2), and Shalimar Wheat-2 (V₃). A seed rate of 80 kg ha⁻¹ and the application of 120 kg N, 80 kg P₂O₅, 60 kg K₂O, and 20 kg ZnSO₄, as recommended by SKUAST Kashmir, 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 tallest tiller's apex. The Leaf Area Index (LAI) was measured at various phenological stages using a Canopy Interception and LAI Analyzer (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 1000-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:

$$HI (\%) = \frac{\text{Economic yield (grain)}}{\text{Straw yield} + \text{grain yield}} \times 100$$

Data processing and statistical analysis

Data were analysed using SAS 9.0²⁴. The Least Significant Difference (LSD) tests were used to compare the treatment means.

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 to a standard normal homogeneity test to ensure that the assumption of linear regression was met²⁵. Likewise, the time series were tested for serial correlation, as this could invalidate the results of the MK test²⁶.

Result and discussion

Climate change in the 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 during

the period 1980-2021 (Figure 3a-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 yearly minimum temperature was also detected in 1996, with warmer temperatures experienced following that date compared to previous decades.

Trends in precipitation

A decreasing trend in total annual precipitation of -4.53 mm/year was detected over Kashmir Valley for 1980-2021 (Figure 3c). 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 & 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 earlier²⁷. Late sowing after the suggested date may also prevent wheat from achieving its full genetic yield potential²⁸.

Effect of sowing date and genotypes on the phenology of wheat

Figure 4 illustrates 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.²⁹ 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 booting, 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 cycle³⁰.

Effect of sowing date and genotypes on wheat yield

Table 4 illustrates 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^{31,32}.

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 variety³¹.

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 October 15 (V₂S₁), followed by Shalimar Wheat-2 (V₃S₁) and SKAU-101 (V₁S₁) 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 November 15 (V₁S₃). Rahman *et al.*³³ also reported a significant decline in the yield of the Shatabdi wheat variety when sowing late (10th December) compared to early sown (20th 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 the implementation of adaptive measures, such as adjustments in crop management techniques and the cultivation of 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. This 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 (October 15), 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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REFERENCES

1. United States Department of Agriculture. Wheat Outlook-WHS-22d, National Agricultural Statistics Service, 2022, pp. 16 of 23
2. FAOSTAT, FAO, 2022: Online: <https://www.fao.org/faostat/en/#data>

3. Saddiq, M.S., Afzal, I., Iqbal, S., Hafeez, M.B. and Raza, A., Low leaf sodium content improves the grain yield and physiological performance of wheat genotypes in saline-sodic soil. *Pesquisa Agropecuaria Tropical*, 2021, **51**: e67663.
4. Wasaya, A., Manzoor, S., Yasir, T.A., Sarwar, N., Mubeen, K., and Ismail, I.A., Evaluation of fourteen bread wheat genotypes by observing gas exchange parameters, relative water and chlorophyll content, and yield attributes under drought stress. *Sustainability*, 2021, **13(9)**: 4799
5. Directorate of Economics and Statistics. Department of Agriculture and Farmers Welfare, Government of India. pp. 2021a, 55 of 457.
6. Kumar, A., Singh, R., Singh, J., Sharma, R.K., Saharan, M.S., Tyagi, B.S., Chand, R., and Sharma, I., Wheat cultivation in India. Pub., Directorate of Wheat Research, Karnal, Extension Bulletin No. **34**, 2014, pp. 34.
7. Sonkar, G., Mall, R.K., Banerjee, T., Singh, N., Kumar, T.V.L., Chand, R., Vulnerability of Indian wheat against rising temperature and aerosols. *Environmental Pollution*, 2019, **254** (Part A): 112946.
8. Mahdi, S.S., Dhekale, B.S. and Sharma, R.P., Weather extremes and their impact on agriculture in India. *Indian Farming*, 2013, **63(3)**: 33-36.
9. Singh, G.P., Ramadas, S. and Krishnappa, G., Maximization of national wheat productivity: challenges and opportunities. In book: Current Trends in Wheat and Barley Research and Development (pp.1-12), 2019, Publisher: ICAR-IARI RS, Indore, India
10. Sukumaran, S., Hari, K., Singh, K., Mottaleb, K.A. and Reynolds M., Progress and prospects of developing climate resilient wheat in South Asia using modern pre-breeding methods. *Current Genomics*, 2021, **22(6)**: 440-449.
11. Directorate of Economics and Statistics. Department of Agriculture and Farmers Welfare, Government of Jammu & Kashmir, 2021b, p. 107 of 923.
12. Khatri, N., Pandey, B.P., Bista, M. and Ghimire, D. L., Effect of different wheat variety and sowing methods on grain yield of wheat under Bhairahawa condition of Nepal. *International Journal of Life Sciences and Biotechnology*, 2019, **2(3)**: 175-82.
13. Nisa, R.U., Bhat, T.A., Sheikh, T.A., Wani, O.A., Bhat, M.A. and Nazir, A., The need for new directions on conservation agriculture towards weed management. *International Research Journal of Pure and Applied Chemistry*, 2020, **21(24)**: 177-91.
14. Chowdhury, M.K., Hasan, M.A., Bahadur, M.M., Islam, Md. R., Hakim, Md. A., Iqbal, M.A., Javed, T., Raza, A., Shabir, R., Sorour, S., Elsanafawy, N.E.M., Anwar, S., Alamri, S., Sabagh, A. EL, and Islam, M.S. 2021. Evaluation of drought tolerance of some wheat

- genotypes through phenology, growth and physiological indices. *Agronomy*, 2021, **11(9)**: 1792.
15. Wasaya, A., Manzoor, S., Yasir, T.A., Sarwar, N., Mubeen, K., and Ismail, I.A., Evaluation of fourteen bread wheat genotypes by observing gas exchange parameters, relative water and chlorophyll content, and yield attributes under drought stress. *Sustainability*, 2021, **13(9)**: 4799.
 16. Marotzke, J. and Forster, P.M., Forcing, feedback and internal variability in global temperature trends. *Nature*, 2015, **517(7536)**: 565-70.
 17. Mahdi, S. S., Jan, R., Jehangir, I.A., Hussain, A., Bhat, M.A., Dhekale, B.S., Ahmad, L., Sofi, N.R., Bangroo, S., Qureshi, A.M.I, Wani, O.A. and Bhar, F.A., Farmer's perception of climate change and adaptation strategies under temperate environmental conditions of Kashmir, India. *Journal of Agrometeorology*, 2021, **23(4)**: 442-451.
 18. Mo, F., Sun, M., Liu, X.Y., Wang, J.Y., Zhang, X.C. and Ma, B., Phenological responses of spring wheat and maize to changes in crop management and rising temperatures from 1992 to 2013 across the Loess Plateau. *Field Crops Research*, 2016, **196**: 337-47.
 19. Asseng, S., Ewert, F., Martre, P. et al. Rising temperatures reduce global wheat production. *Nat. Clim. Change*, 2015, **5**:143-147.
 20. Paymard, P., Yahoubi, F., Nouri, M. and Bananayan, M., Projecting climate change impacts on rainfed wheat yield, water demand, and water use efficiency in northeast Iran. *Theoretical and Applied Climatology*, 2019, 138: 1361-1373.
 21. Zhao, B. Liu, S. Piao, D.B. Lobell, Y. Huang, et al., Temperature increase reduces global yields of major crops in four independent estimates. *Proc. Natl. Acad. Sci. U.S.A*, 2017, **114**: 9326-31.
 22. Liu, K., Matthew, T.H., Bin, W., Rui, Y., Haoliang, Y., Juan, Z., De, L. L., Holger, M., Xiaohai, Tian., Shangyu, M., Yunbo, Z., Jianguo, M., Xiaoyan, W. and Meixue, Z., Designing high yielding wheat crops under late sowing: a case study in Southern China. *Agronomy for Sustainable Development*, 2022, **42(29)**: 22-32.
 23. Waha, K., Muller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P. and Heinke, J., Climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change*, 2013, **23(1)**: 130-43.
 24. SAS., Statistical Analysis System User's Guide: Statistical Version. 8th Edition, 2003, SAS Institute, Cary.
 25. Kang, H. M. and Yusof, F., Homogeneity tests on daily rainfall series. *Int. J. Contemp. Math. Sciences*, 2012, **7(1)**: 9-22.

26. Yue, S., Pilon, P. and Cavadias, G., Power of the Mann–Kendall and Spearman's Rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, 2002, **259(1-4)**: 254-271.
27. Tewari, S. and Singh, M., Influence of sowing date on phase duration and accumulation of dry matter in spikes of wheat. *Indian Journal of Agronomy*, 1995, **40(1)**: 43-6.
28. Liu, K., Matthew, T.H., Bin, W., Rui, Y., Haoliang, Y., Juan, Z., De, L. L., Holger, M., Xiaohai, Tian., Shangyu, M., Yunbo, Z., Jianguo, M., Xiaoyan, W. and Meixue, Z. Designing high yielding wheat crops under late sowing: a case study in Southern China. *Agronomy for Sustainable Development*, 2022, **42(29)**: 22-32.
29. Deng, W.W., Casao, M.C., Wang, P.H., Sato, K., Hayes, P.M., and Finnegan, E.J., Direct links between the vernalization response and other key traits of cereal crops. *Nat Commun*, 2015, **6**: 5882.
30. Wahid, A., Gelani, S., Ashraf, M. and Foolad, M.R., Heat tolerance in plants: An overview. *Environmental and experimental botany*, 2017, **61(3)**: 199-223.
31. Tahir, M., Ali, A., Nadeem, M.A., Hussain, A. and Khalid, F., Effect of different sowing dates on growth and yield of wheat varieties in district Jhang, Pakistan. *Pak. J. Life Soc. Sci.* 2009, **7(1)**: 66-69
32. Habibi, A. and Fazily, T., Effect of sowing dates on growth, yield attributes and yield of four wheat varieties. *EPRA International Journal of Research and Development*, 2020, **5(1)**: 56-59.
33. Rahman, M.A., Mohabbatullah, M., Das, C.K., Sarker, U.K., and Alam, S.M.M., Sowing time and varietal wheat performance at higher elevation in hill environment at Khagrachari. *Bangladesh Journal of Agricultural Research*, 2015, **40(4)**: 521-528

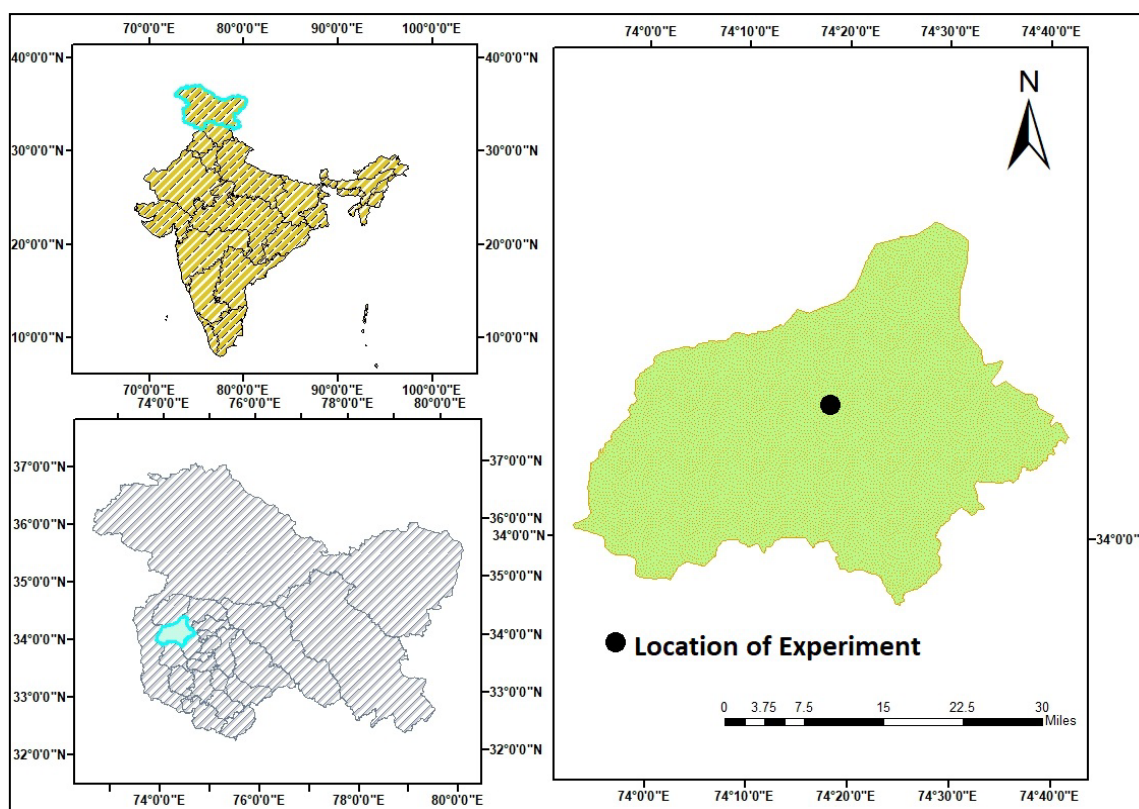


Figure 1. The location of the experimental site at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir (SKUAST-K), Wadura Campus

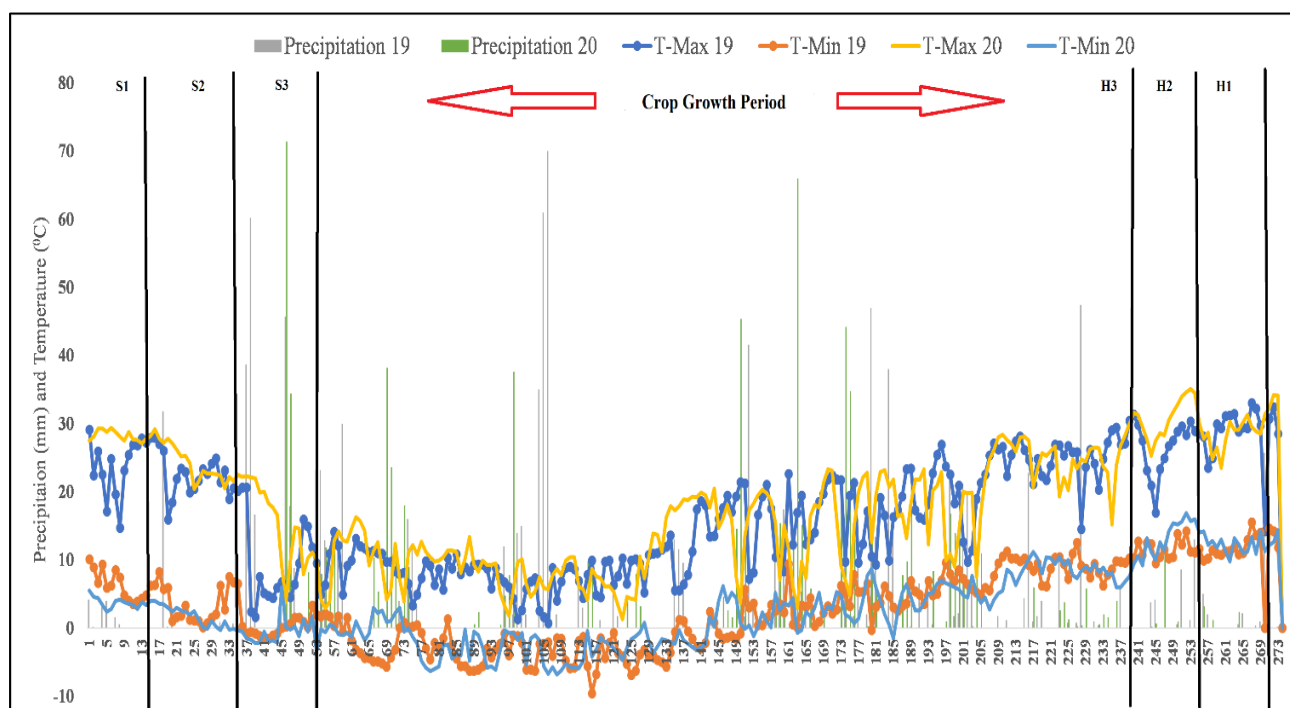


Figure 2. Mean daily weather data from October 2019-June 2020 & October 2020-June 2021 (S1, S2, and S3 indicate sowing dates, and H1, H2, and H3 indicate crop harvesting dates).

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

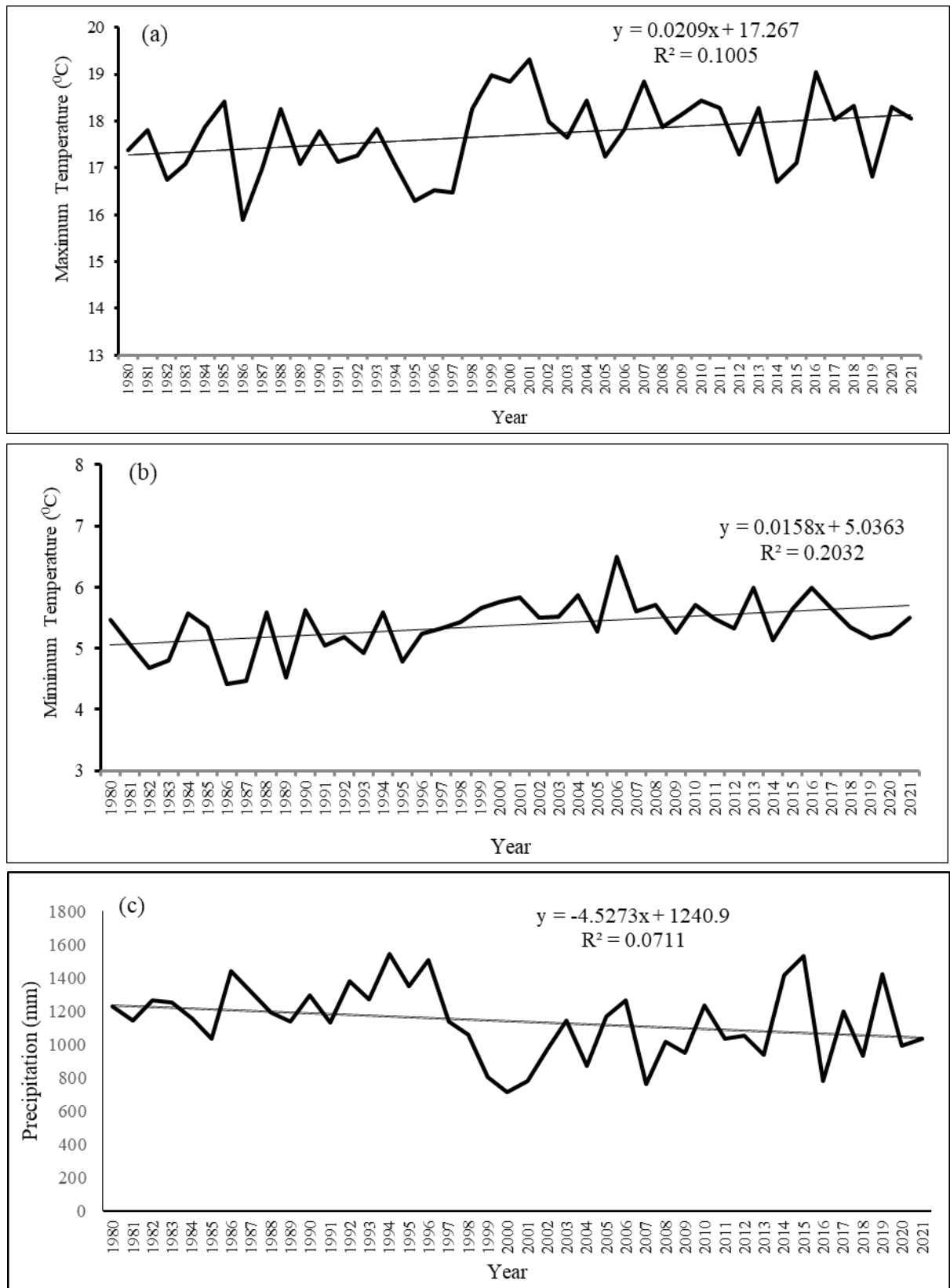


Figure 3: Annual trends in the maximum (a) and minimum temperatures (b) and precipitation (c) at a weather station in the Kashmir Valley during the period 1980-2021

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)
<i>Sowing dates</i>							
15 th October (S ₁)	22.67	58.93	90.26	95.94	100.93	101.66	101.69
1 st November (S ₂)	21.04	57.35	85.94	92.89	98.09	98.71	98.76
15 th 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
<i>Genotypes</i>							
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

Table 3. The effect of sowing dates and genotypes on LAI 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
<i>Sowing dates</i>							
15 th October (S ₁)	1.67	2.90	3.64	3.97	3.62	2.94	2.91
1 st November (S ₂)	1.64	2.42	3.52	3.83	3.48	2.79	2.76
15 th 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
<i>Genotypes</i>							
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

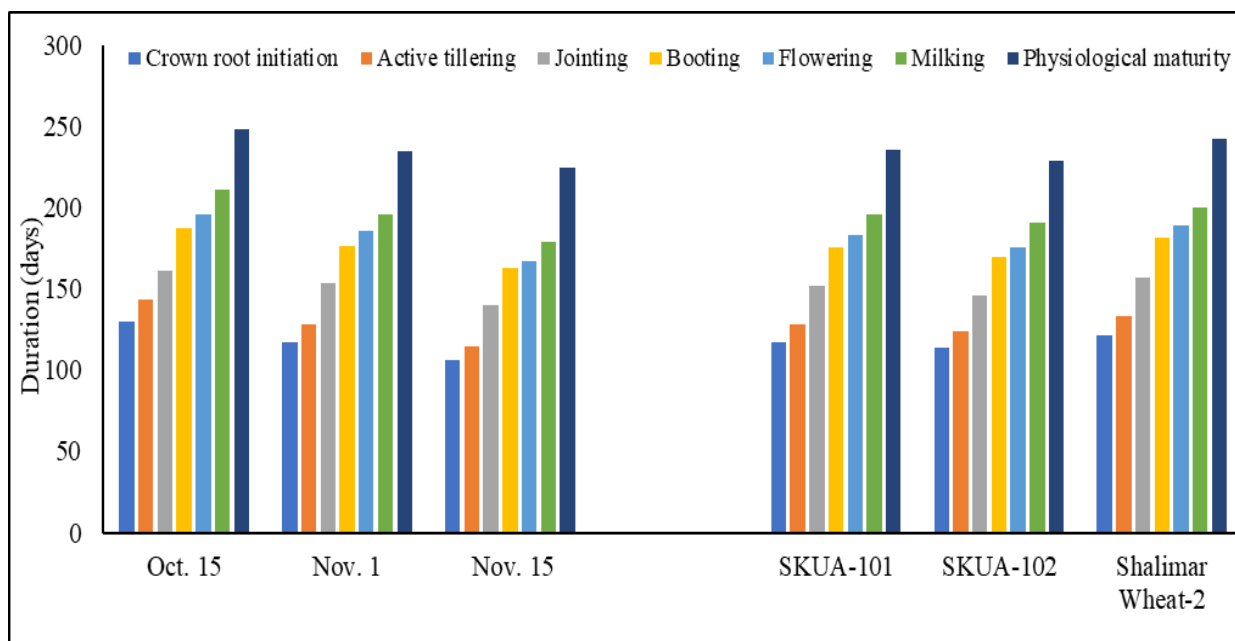


Figure 4. The effect of sowing dates and genotypes on different phenological stages of wheat during 2020 and 2021.

Table 4: Effect of sowing dates and genotypes on wheat grain and straw yield and Harvest Index for 2020 and 2021

Treatments	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Harvest Index (%)
<i>Sowing dates</i>			
15 th October (S ₁)	4.01	7.54	34.65
1 st November (S ₂)	3.57	7.04	33.57
15 th November (S ₃)	2.73	6.28	30.30
SEm±	0.05	0.01	0.35
CD (<i>p</i> ≤0.05)	0.18	0.04	1.07
<i>Genotype</i>			
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(<i>p</i> ≤0.05)	0.18	0.04	0.93

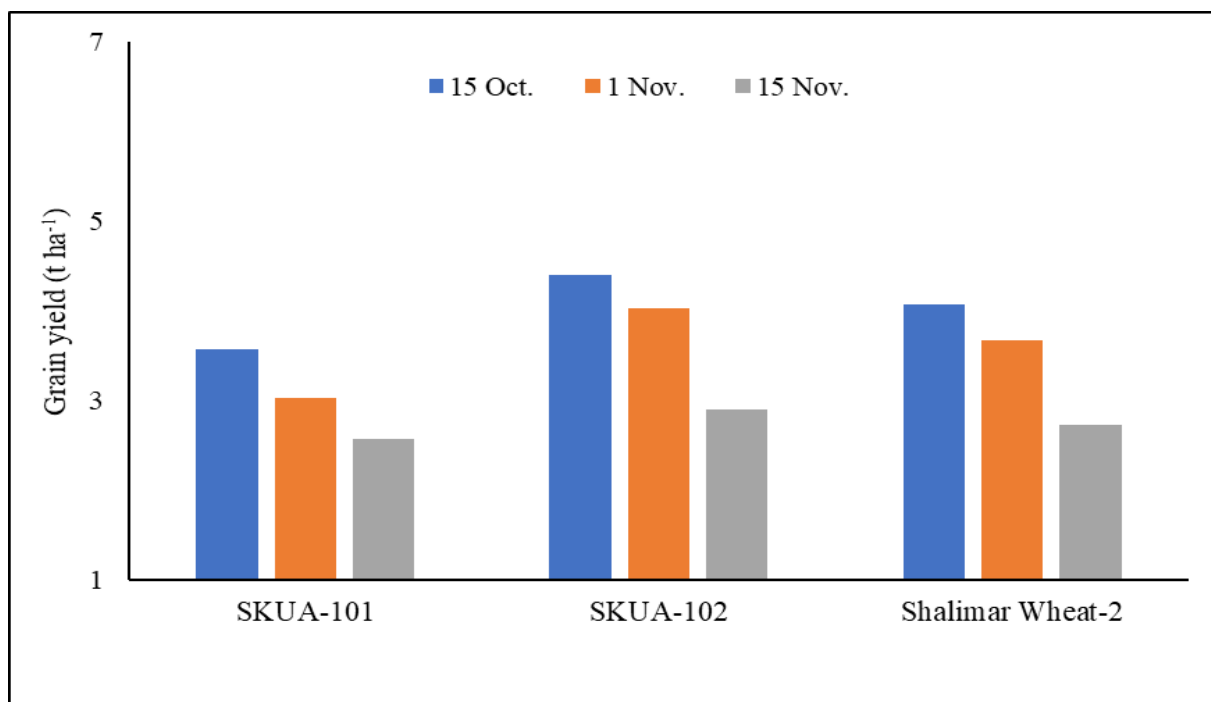


Figure 5. The interaction effect of sowing dates and genotypes on wheat grain yield during 2020 and 2021