

Improving the Growth and Productivity of Barley through Genotypes and Sowing Time Scheduling in Sub-tropical Humid Climate

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Abstract

The agricultural productivity needs to be improved substantially to meet the food demand of burgeoning population from same or even reduced land resources amidst the climate change. To address these challenges, systematic efforts are required on devising high yielding genotypes and adopting suitable agronomic measures. The present study was undertaken to examine the role of genotypes and sowing time scheduling on growth and productivity of barley. The multi-locational field experiment was conducted in split-plot design with four sowing window (26th October-5th November, 6-15th November, 16-25th November and 26th November - 5th December) in main-plots and two barley genotypes (BH 946 and DWRB 160) in sub-plots with three replications during the *Rabi* seasons of 2020-21 and 2021-22. The results revealed that both sowing window and genotypes had significant effect on plant height, earhead density, grains per earhead, 1000-grain weight, biomass and yield. The sowing window beyond 15th November made drastic reduction in earhead density, 1000-grain weight, biomass and yield. The more number of grains per spike in BH 946 made it superior in terms of yield over DWRB 160. The effect of sowing window × genotype interaction on grain yield was significant. In the north-western plains zone, a one-month delay in sowing window (from the last week of October to the last week of November) resulted in a yield penalty of 11.2-40.7%. Therefore, a synchronized sowing window should be adopted for high yielding genotypes to realize the improvement in the productivity of barley.

Keywords: Yield, sowing window, earhead density, heat stress, early sowing

1. Introduction

Barley (*Hordium Vulgare* L.) is the fourth most important cereal crop grown worldwide on approximately 49.2 million hectares (m ha) with a production of 145.8 million tonnes (Mt) (USDA, 2023) and is considered as one of the most nutritious foods. The multipurpose use of barley

in food, feed and industrial products such as malt and its lesser water requirement are considered prominent reasons for the growing interest of farming communities especially in heat stress and less resources rich regions. Barley occupied an area of 0.608 m ha with a production



of 1.919 Mt in India during 2024-25 (DA&FW, 2025). It holds a great potential in India due to diverse agro-climatic conditions and majorly grown in the states of Rajasthan, Uttar Pradesh, Madhya Pradesh, Himachal Pradesh, Haryana, Uttarakhand and Punjab. Rajasthan occupied about 54.3% of total barley area while holding 63.7% share in total barley production during 2024-25 (DA&FW, 2025). Despite the adaptive potential of barley, its productivity often remains below across these states due to older varieties in practice and inappropriate agronomic measures. Climate variability has further intensified these challenges, thereby necessitating refined agronomic strategies along with high yielding cultivars to sustain and enhance the barley productivity (Prasad *et al.*, 2017). Several studies have clearly demonstrated that barley productivity is strongly influenced by genotypic differences under diverse agro-climatic conditions. Newton *et al.* (2011) reported that substantial variability exists among barley genotypes in terms of grain yield, biomass production, and harvest index, reflecting differential adaptation to temperature and moisture regimes. The findings emphasized that genotypes with greater phenological flexibility and stress tolerance mechanisms tend to perform more consistently across environments. Similarly, Reynolds *et al.* (2011) highlighted that genotypic differences in assimilate partitioning and grain filling duration significantly contribute to yield variation, particularly under heat-stressed conditions. Oosterom *et al.* (1993), working in variable and stress-prone environments, found that barley genotypes differed significantly in tillering ability, spike number, and grain weight, leading to marked differences in final grain yield. It was reported that locally adapted and stress-tolerant genotypes often outperformed high-yielding but less resilient cultivars, underscoring the importance of genotype selection for specific environments. Bhagat *et al.* (2023) also observed significant genotypic effect on differences among barley genotypes on plant height, number of effective tillers, grain yield, and stress tolerance indices, indicating that certain genotypes were better suited to cope with high temperature stress during the reproductive stages. Genetic variability within barley germplasm provides opportunities to improve crop performance under diverse and changing environments. Barley genotypes differ markedly in growth habit, phenological duration, tillering ability, biomass accumulation, grain filling efficiency, and

tolerance to biotic and abiotic stresses (Oosterom *et al.*, 1993). Genes regulating the flowering time and maturity play a critical role in synchronizing crop development with prevailing environmental conditions, thereby influencing yield stability and adaptation (Maurer *et al.*, 2015). These studies collectively indicate that genetic improvement and appropriate genotype selection are critical for maximizing the barley productivity, particularly in environments characterized by climatic variability.

The cultivation of high yielding genotypes with suitable agronomic measures can bridge the gap between potential and actual productivity of barley. Among agronomic practices, sowing time is considered as one of the most influential factors affecting barley growth and yield. Timely sowing allows barley plants to exploit optimal temperature and radiation conditions, resulting in improved vegetative growth, higher photosynthetic efficiency, and enhanced assimilate translocation to developing grains. Conversely, delayed sowing often shortens the crop growth duration and exposes sensitive reproductive stages to heat stress and excessive humidity, leading to poor grain set, reduced grain weight, and overall yield decline (Bhagat *et al.*, 2023). Several studies have documented that delayed sowing significantly reduces plant height, number of effective tillers, leaf area index, dry matter accumulation, and grain yield of barley due to accelerated phenological development and reduced grain filling duration (Rawat *et al.*, 2025). Tahir *et al.* (2009) reported that delay in sowing time affected germination, growth and grain development, and produced poor tillering due to winter injury in low temperatures, resulting in suppressed yield. The reduced yield under late sown condition is generally associated with a reduced kernel weight (Radmehr *et al.*, 2003), a reduced number of spikes per plant per unit area (Stapper and Fischer, 1990), harvest index, grain number per spike, and leaf area index (Jessop and Ivins, 1970). The interaction between genotype and sowing time is particularly important in determining barley performance under variable climatic conditions. While some genotypes perform well under early or timely sowing, others may be better adapted to slightly delay sowing due to their longer grain filling duration or heat tolerance traits (Oosterom *et al.*, 1993). Understanding these genotype \times management interactions is essential for identifying stable, high-yielding genotypes and optimizing sowing schedules tailored to specific agro-ecological conditions. A limited information



is available on the combined influence of barley genotypes and sowing time scheduling on growth dynamics and productivity. Most existing studies focus either on varietal performance or sowing date by considering only two sowing time frames i.e. timely and late sown condition. The combined study of genotype selection and systematic sowing time scheduling may provide insights on optimum sowing window period and genotype \times managements effects on the productivity of barley. Therefore, the present investigation was undertaken to assess the effects of different barley genotypes and sowing time schedules on growth, and productivity of barley under a sub-tropical humid climate. The study was focused on research hypothesis which states that sowing window can affect productivity of barley crop. This study aims to identify suitable genotype-sowing time combinations that maximize barley growth and productivity, thereby providing scientifically sound recommendations for farmers and contributing to sustainable barley production in similar agro-ecological regions.

2. Materials and Methods

2.1 Details of experimental site

A field experiment was conducted during the *Rabi* seasons of 2020-21 and 2021-22 to study effect of sowing window (26th October-5th November, 6-15th November, 16-25th November, 26th November - 5th December) and genotype (BH 946 and DWRB 160) on growth and productivity of barley. The field experiment was conducted in a split-plot design with three replications using four sowing window in the main-plots and two genotypes in the sub-plots. The selected sowing windows of 26th October-5th November, 6-15th November, 16-25th November and 26th November - 5th December in this study represent early, timely, moderately late and late sown conditions, respectively. This multi-locational field experiment was conducted at Karnal, Agra, Durgapura, Hisar and Ludhiana centres in the north-western plains of India which occupied sandy loam and loamy sand soils. The soil properties of these locations are given in Table 1. These soils carried low levels of organic carbon and total nitrogen while medium availability of phosphorus and medium-high availability of potassium in the upper layer (0-15 cm).

Table 1: Soil properties of locations used in the present study

Location	Soil texture	Sand, %	Silt, %	Clay, %	Avail N, kg ha ⁻¹	Avail, P kg ha ⁻¹	Avail K, kg ha ⁻¹	pH	OC, %
Hisar	Sandy loam	72.0	18.5	9.5	147.0	16.9	270.0	7.7	0.34
Durgapura	Loamy sand	80.9	9.9	7.7	155.3	38.1	210.6	8.1	0.26
Karnal	Sandy loam	52.5	29.2	18.4	184.3	16.1	190.7	8.1	0.42
Ludhiana	Loamy sand	83.5	8.0	8.5	NA*	36.8	128.8	7.3	0.43
Agra	Sandy loam	60.7	20.4	18.5	178.7	27.9	279.4	8.3	0.39

NA: Not available

2.2 Weather details

The weather parameters *viz.* maximum temperature, minimum temperature and rainfall of experimental sites during 2020-21 and 2021-22 are presented in Fig. 1 and 2, respectively. During the grain filling period (mid-February to March), the range of maximum temperature was 27.0-40.0° at Agra, 25.9-37.1° at Durgapura, 24.8-37.5° at Hisar, 22.5-35.6° at Ludhiana and 21.5-36.3° at Karnal location in both the experimental years. However, temperature during the grain filling period was more in 2021-22 than 2020-21. During the crop growing season, Karnal received exceptional high rainfall of 315.9 mm in

2020-21 while lowest rainfall (9.0-35.0 mm) was observed at Agra location during both the years.

2.3 Crop management and data recording

Barley crop was sown with precision plot drill at a row spacing of 23 cm. The normalized seed rate of 100 kg ha⁻¹ (adjusted according to 1000-grain weight by taking 45 g weight as normalized test weight) was used in the present study. The crop was fertilized with recommend rate of N, P₂O₅, K₂O @60:30:20 kg ha⁻¹ in BH 946, a six-row barley genotype and @90:40:30 kg ha⁻¹ in DWRB 160, a two-row barley genotype. The half dose of the nitrogen, and full dose of phosphorus and potassium was applied



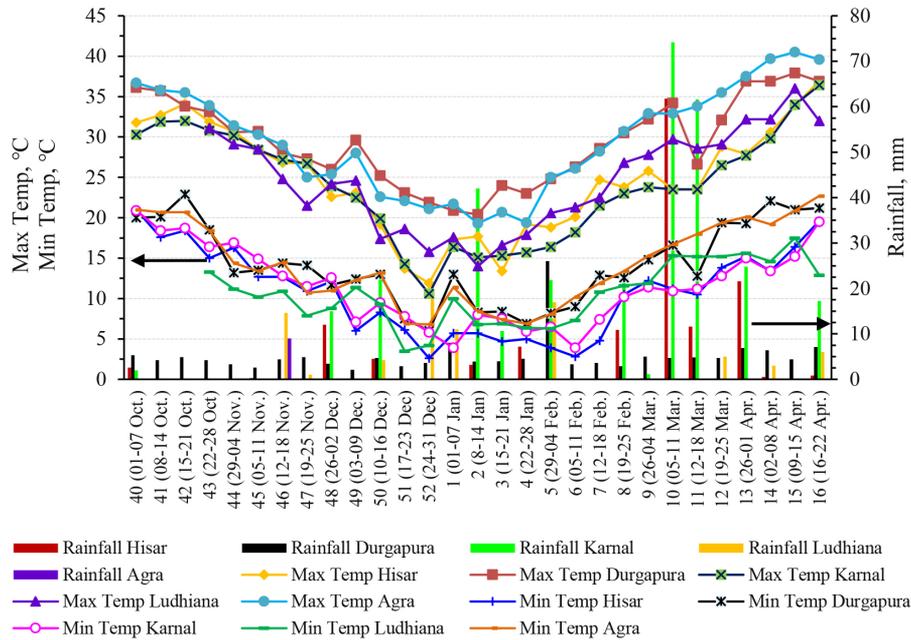


Fig. 1: Location-wise weather parameters during the crop growth period in 2020-21

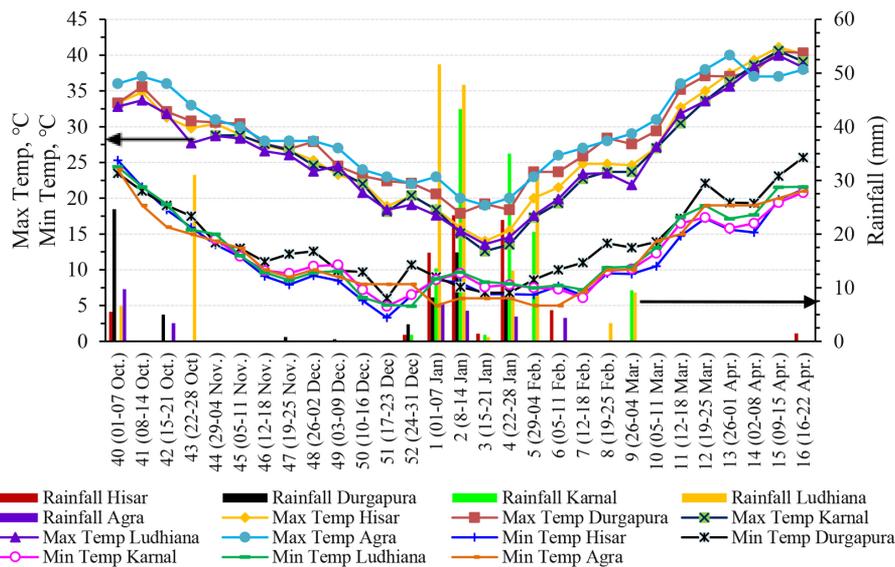


Fig. 2: Location-wise weather parameters during the crop growth period in 2021-22

as a basal dose while the remaining nitrogen was applied during the maximum tillering at 30-35 days after sowing. The crop was given 2-4 irrigations as per the requirement and agro-climatic conditions of the centres. Weed control measures were followed as per recommendations of the zone. Observations for plant height, yield and yield attributing traits were recorded for each plot. The net-plot was harvested manually using sickles by leaving the border rows and one meter length at each end of the plot

in longitudinal direction. For every plot, threshing was done in a small plot thresher. The moisture present in the grains was determined according to Indian Standard IS: 4333-2 (2002), which was then used to correct the grain yield at a standard moisture content of 12% using Eq. 1. For determining 1000-grain weight, grains were counted on an optical seed counter (make: Pfeuffer, model: Contador, Germany) and then weighing on an electronic weighing balance.



$$\text{Corrected grain yield (q ha}^{-1}\text{)} = \text{Harvest yield (q ha}^{-1}\text{)} \times \frac{\{100-\text{harvest moisture}(\%)\}}{\{100-\text{standard moisture}(\%)\}}$$

2.4 Data analysis

The experimental data were subjected to analysis of variance to see the treatment means. Based on the significance of the F-test, means of different treatments were compared with Fisher's least significant difference test at a significance level of 5% ($\alpha = 0.05$). The comparison of the two treatments was done using 'Fischer's paired t-test. Similar results of experimentation over the years were pooled to understand the overall impact.

3. Results and Discussion

3.1 Effect of sowing window and genotype on yield attributes

The effects of sowing window and genotype on yield attributes are shown in Table 2. It can be observed that both sowing window and genotype introduced significant effect ($p < 0.05$) on plant height of barley. The plant height was similar ($p \geq 0.05$) for crop sown in the first three windows (25th Oct-25th Nov); however, it reduced significantly when sowing was delayed beyond 25th Nov i.e. late sown situation. Both Tewari and Singh (1995), and Tahir *et al.* (2009) reported that crops sown at a late time had shorter plant heights. On the mean basis, the plant height of BH 946 was more over DWRB 160. Sowing window, genotype and their interaction significantly influenced the earheads per unit area. The successive delay in sowing caused significant decrease in earhead density, registering 316 earheads m⁻² under later sown situation as compared to 375-392 earheads m⁻² with early and timely sown crop. Under comparable agro-climatic conditions, Prabhakar *et al.* (2007) and Kumar (2012) also documented a decline in the number of tillers with repeated delays in the sowing time. Across all the sowing windows, more earhead density was registered for DWRB 160 in comparison to BH 946. Grains per earhead were significantly affected by sowing window, genotype and their interaction. On the mean basis, the lowest grain bearing was observed under late sown condition; however, it was at par ($p \geq 0.05$) to early sown condition. The number of grains were significantly higher under timely and moderately late sown situations in comparison with early and later sown conditions. The timely sowing circumstance gives the crop enough time for vegetative growth, which results in more grains per

spikelet. Unlike to findings of this study, Behera (1994) reported more grains per spikelet for early sown wheat crop. Owing to six-row nature, more grains per earhead (47.4 grains per earhead) were recorded for BH 946 over DWRB 160 (two-row genotype) having 30.1 grains per earhead on the mean basis. Based on the pooled data, the successive delay in sowing made significant decline in 1000-grain weight, registering 47.63, 46.33, 44.04 and 41.15 g weight for early, timely, moderately late and late sown conditions, respectively. In all the sowing windows, both genotypes recorded lesser 1000-grain weight during 2021-22 as compared to 2020-21 with lowest difference in 1000-grain weight observed for early sown condition. This phenomenon might be associated with increased maximum temperature during the grain filling period in 2021-22 as discussed in section 2.2 and the early sown crop could experience lesser detrimental effect of terminal heat stress. Chhokar *et al.* (2023) also reported that early sowing may be helpful to reduce the impact of terminal heat stress in high yielding long duration wheat cultivars. Also, a significantly higher 1000-grain weight was recorded for early sown wheat crop compared to timely sown condition in that study. The grains were bolder for DWRB 160 (1000-grain weight as 48.9 g) as compared to BH 946 having 1000-grain weight of 40.6 g. Sowing window, genotype and their interactions made significant variation in biomass yield of the crop. The biomass was similar ($p \geq 0.05$) for early as well as timely sown crop; however, it reduced significantly for moderately late and late sown conditions. These results are in-line with findings given by Tyagi *et al.* (2004). Across all sowing windows, BH 946 produced more biomass (mean 115.6 q ha⁻¹) over DWRB 160 (mean 108.9 q ha⁻¹).

3.2 Effect of sowing window and genotype on grain yield

Sowing window, genotype and their interaction produced significant effect ($p < 0.05$) on grain yield. The effect of sowing window on grain yield is depicted in Fig. 3. The mean grain yield was similar ($p \geq 0.05$) for barley crop sown under early and timely conditions. A further delay in sowing time beyond 15th November i.e. under moderately late and late condition brought 8.2 and 21.2% decline in grain yield, respectively as compared to early sown situation. The decline in grain yield of crop sown beyond timely condition was associated with sharp decline in earhead density, biomass accumulation and 1000-grain



Table 2: Effect of sowing window, genotype and their interaction on yield attributes of barley

Genotype	2020-21				2021-22				Mean			
	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Nov –05 th Dec	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Nov – 05 th Dec	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Nov – 05 th Dec
	Plant height, cm											
BH 946	122	123	121	115	123	122	122	114	122.5	122.5	121.5	116.8
DWRB 160	118	117	116	112	119	118	117	110	118.5	117.5	116.5	112.8
Mean	120	120	118.5	113.5	121	120	119.5	112.0	120.5	120.0	119.0	112.8
CD (0.05)	Sowing Window (A)	2.9	Genotype (B)	2.8	Sowing Window (A)	3.1	Genotype (B)	3.0	Sowing Window (A)	2.9	Genotype (B)	2.9
	B within A	NS	A within B	NS	B within A	NS	A within B	NS	B within A	NS	A within B	NS
Earheads m²												
BH 946	395	379	341	314	376	370	327	285	386	375	334	300
DWRB 160	407	383	375	355	391	365	347	308	399	374	361	332
Mean	401	381	358	335	383	368	337	296	392	375	348	316
CD (0.05)	Sowing Window (A)	11.7	Genotype (B)	7.22	Sowing Window (A)	8.49	Genotype (B)	4.41	Sowing Window (A)	10.2	Genotype (B)	6.2
	B within A	14.4	A within B	15.5	B within A	8.82	A within B	10.5	B within A	11.8	A within B	13.7
Grains earhead⁻¹												
BH 946	47.60	49.60	51.21	45.92	44.37	49.14	47.75	43.23	45.99	49.37	49.48	44.57
DWRB 160	28.14	29.39	29.83	29.24	30.59	31.46	29.97	31.81	29.37	30.43	29.9	30.52
Mean	37.87	39.50	40.52	37.58	37.48	40.30	38.86	37.52	37.68	39.9	39.69	37.55
CD (0.05)	Sowing Window (A)	1.06	Genotype (B)	0.78	Sowing Window (A)	1.77	Genotype (B)	1.79	Sowing Window (A)	1.36	Genotype (B)	1.21
	B within A	1.56	A within B	1.53	B within A	NS	A within B	NS	B within A	1.20	A within B	1.31



	1000-grain weight, g													
	2020-21			2021-22			2020-21			2021-22				
Genotypes	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Nov – 05 th Dec	
BH 946	43.28	43.60	41.62	39.85	42.77	39.79	38.48	35.61	43.03	41.70	40.05	37.73		
DWRB 160	54.46	53.42	50.45	46.70	49.99	48.50	45.61	42.44	52.23	50.96	48.03	44.57		
Mean	48.87	48.51	46.03	43.27	46.38	44.14	42.05	39.02	47.63	46.33	44.04	41.15		
CD (0.05)	Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A	
	0.99	0.99	Genotype (B) A within B	0.75	Genotype (B) A within B	1.50	Genotype (B) A within B	1.45	NS	1.45	NS	1.19	Genotype (B) A within B	1.10
	1.17	1.17	A within B	1.45	B within A	NS	A within B	NS	B within A	1.05	A within B	1.17	A within B	1.17
	Biomass, q ha ⁻¹													
BH 946	118.0	121.0	112.0	105.0	119.0	123.0	113.0	114.0	118.5	122.0	112.5	109.5		
DWRB 160	112.0	114.0	108.0	101.0	111.0	110.0	105.0	110.0	111.5	112.0	106.5	105.5		
Mean	115.0	117.5	110.0	103.0	115.0	116.5	109.0	112.0	115.0	117.0	109.5	107.5		
CD (0.05)	Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A	
	2.7	2.7	Genotype (B) A within B	2.5	Genotype (B) A within B	2.8	Genotype (B) A within B	2.6	2.6	2.7	Genotype (B) A within B	2.5	2.5	
	4.1	4.1	A within B	4.5	B within A	4.3	A within B	4.5	B within A	4.1	A within B	4.5	4.5	

Table 3: Interaction effect of sowing window and genotype on grain yield of barley

Genotypes	2020-21						2021-22						Mean	
	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Oct – 05 th Nov	06-15 th Nov	16-25 th Nov	26 th Nov – 05 th Dec	06-15 th Nov	16-25 th Nov	26 th Nov – 05 th Dec	Mean
BH 946	47.56	48.66	48.08	42.15	48.86	49.57	42.93	34.97	48.21	49.12	45.51	38.56		
DWRB 160	45.23	45.13	45.38	37.81	43.67	44.03	36.62	32.75	44.45	44.58	41.0	35.28		
Mean	46.40	46.89	46.73	39.98	46.27	46.80	39.78	33.86	46.33	46.85	43.25	36.92		
CD (0.05)	Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A			Sowing Window (A) B within A	
	1.22	1.22	Genotype (B) A within B	0.65	Genotype (B) A within B	1.18	Genotype (B) A within B	0.69	0.69	1.21	Genotype (B) A within B	0.66	0.66	
	1.29	1.29	A within B	1.52	B within A	1.38	A within B	1.53	B within A	1.32	A within B	1.52	1.52	



weight under moderately late and late sown situations. Based on the pooled data, the mean grain yield under early, timely, moderately late and late sown conditions was recorded to be 46.65, 46.77, 42.83 and 36.74 q ha⁻¹, respectively. In a study, Ram *et al.* (2010) observed similar yield (55.2-56.5 q ha⁻¹) of barley crop on early sown (15th October) and timely condition (15th November) but drastic reduced yield (39.4 q ha⁻¹) of crop sown on 15th December. Chaudhary *et al.* (2017) also reported similar tillers density, grains per earhead, test weight and yield of barley crop sown on 30th October and 10th November but these were sharply declined with 10th December sowing date. Chhokar *et al.* (2023) found increased yield and bolder grains of wheat when sown under early condition.

The effect of genotype on mean grain yield is illustrated in Fig. 4. The result showed that BH 946 performed better in terms of yield (45.25 q ha⁻¹) over DWRB 160 (41.25 q ha⁻¹) mainly due to its six-row nature and thus more grains being present per spikelet. The effect of sowing time × genotype interaction on yield is presented in Table 3. It is interesting to see that grain yield of both genotypes decreased sharply on shifting from timely sown condition to moderately late condition during 2021-22 as discussed in section 2.2 and Fig. 2. The importance of non-monetary inputs such as sowing time on grain yield can be realized more effectively during years which experience high temperature from mid-February to March months.

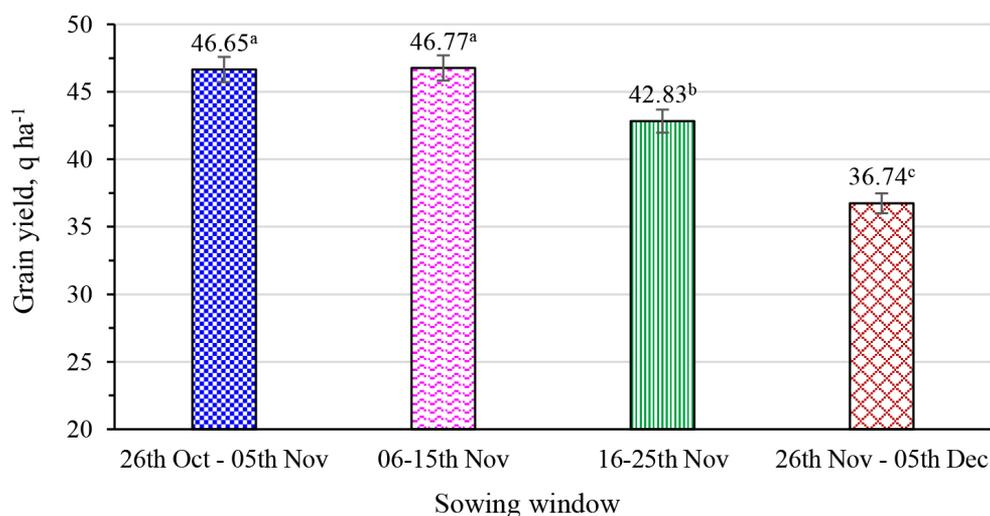


Fig. 3: Effect of sowing window on grain yield of barley

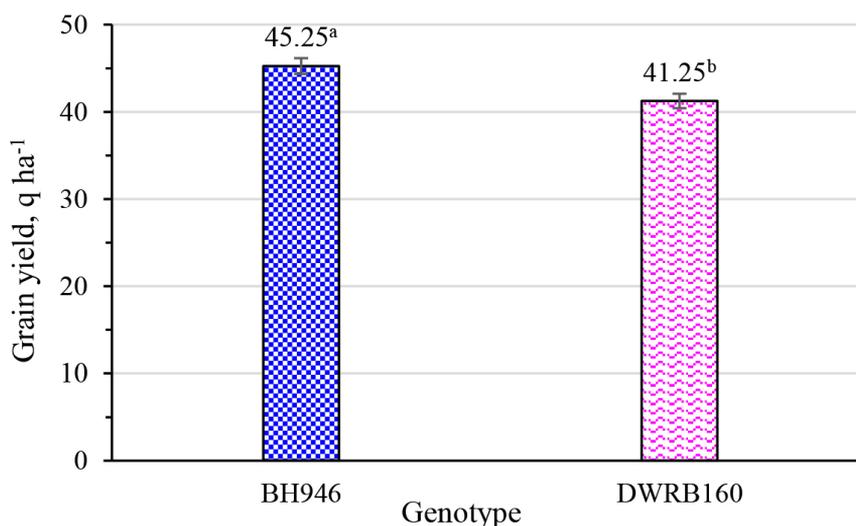


Fig. 4: Effect of genotype on grain yield of barley



4. Conclusions

Amidst the climate vagary situations, it is crucial to adopt the integrated approach of high yielding genotypes along with suitable agronomic measures to realize the improvement in barley productivity. Considering this, the present study was undertaken on improving the growth and productivity of barley through genotypes and sowing time scheduling in sub-tropical humid climate, which led to the following concluding remarks:

Sowing window had significant effect on growth and yield attributes of barley, suggesting sharp decline in earhead density, 1000-grain weight, biomass accumulation and yield of barley sown beyond 15th November under moderately late and late situations.

The mean grain yield reduced to 42.8 and 36.7 q ha⁻¹ under moderately late and late sown situations, respectively, as compared to 46.7 q ha⁻¹ under early and timely sown conditions.

Genotype BH 946 performed superiorly with a mean grain yield of 45.25 q ha⁻¹ over DWRB 160 (41.25 q ha⁻¹) in association with dominant effect of more grains per spikelet.

Significant effect of sowing window × genotype interaction was observed for all growth and yield attributing traits except plant height.

It can be concluded that sowing of high yielding barley cultivars should not be delayed beyond 15th November (timely sown condition) to avoid the yield penalty in north-western plains zone. Moreover, early sowing may be a good strategy to lessen the detrimental effect of heat stress during the grain filling phase of barley.

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Author Contributions

ASK: designed and conducted the experiment, performed statistical analysis and wrote manuscript draft, HR: conducted the experiment, BS: conducted the experiment, MRY: conducted the experiment, SBS: conducted the experiment, NK: made graphs, reviewed and edited the manuscript, SC: conducted the experiment and reviewed the manuscript, GS: overall supervision

Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

The article doesn't contain any study involving ethical approval.

Use of Generative AI or AI assisted technologies

Authors declare that no Generative AI or AI assisted technologies have been used in preparation of this manuscript.

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