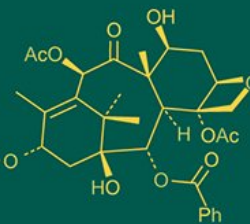
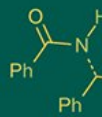


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Multi-location evaluation of elite bread wheat (*Triticum Aestivum* L.) genotypes for grain yield and agronomic performance under timely sown conditions in Madhya Pradesh

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Abstract

Wheat (*Triticum aestivum* L.) is a major cereal crop that plays a vital role in global food security. Identifying high-yielding and well-adapted genotypes under optimum sowing conditions is essential for developing improved wheat cultivars with enhanced productivity. The present investigation was conducted during the Rabi season of 2025-2026 at two locations in Madhya Pradesh, India, namely the Borlaug Institute for South Asia (BISA), Jabalpur, and Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore, to evaluate the agronomic performance and grain yield potential of elite wheat genotypes under timely sown conditions. Thirty elite bread wheat genotypes, along with two check varieties, DBW-187 and Lok-1, were evaluated using a Randomized Block Design with two replications.

Observations were recorded for germination percentage, ground cover, days to heading, days to anthesis, days to maturity, plant height, spike length, biomass, grain yield, and harvest index. Analysis of variance revealed significant differences among the evaluated genotypes for the studied traits, indicating the presence of substantial genetic variability. Considerable variation in agronomic performance and grain yield was observed across the two experimental locations. Among the tested entries, genotype 8033 (NINGA #1) consistently exhibited superior performance at both locations, recording the highest grain yield of 68.52 q ha⁻¹ at BISA, Jabalpur, and 68.23 q ha⁻¹ at SVVV, Indore. The superior performance of this genotype was accompanied by favourable phenological characteristics, longer spikes, and higher biomass production.

The findings demonstrate the potential of genotype 8033 as a promising high-yielding wheat line under timely sown conditions. The superior-performing genotypes identified in this study may serve as valuable genetic resources for wheat improvement programmes and further multi-environment evaluation.

Keywords: Wheat, timely sown conditions, genotype evaluation, genetic variability, grain yield, multi-location evaluation, wheat breeding.

Introduction

Wheat (*Triticum aestivum* L.) is one of the world's most important cereal crops, providing nearly 20% of the calories and protein consumed by the global population (Shiferaw *et al.*, 2013; FAO, 2024) [10, 29]. In India, wheat is the second most important staple crop after rice and plays a vital role in ensuring food and nutritional security (Directorate of Economics and Statistics, 2023; Erenstein *et al.*, 2022) [7, 8]. With increasing demand driven by population growth, the development of high-yielding and climate-resilient wheat cultivars has become a major objective of wheat improvement programmes (Reynolds *et al.*, 2021; CIMMYT, 2023) [25]. Genetic variability is the foundation of any successful crop breeding programme because it provides opportunities for selecting superior genotypes with desirable agronomic traits (Allard, 1999; Falconer and Mackay, 1996) [1, 9]. Evaluation of elite breeding materials under optimum growing conditions is an essential step for identifying high-yielding and stable genotypes that can be used either as promising cultivars or as parental lines in future breeding programmes (Reynolds *et al.*, 2012; Lopes and Reynolds, 2010) [20, 24]. Timely

sowing allows wheat plants to complete their vegetative and reproductive phases under favourable environmental conditions, enabling the expression of their full genetic yield potential (Sharma *et al.*, 2023; Joshi *et al.*, 2007) [16, 27, 28].

Grain yield in wheat is a complex quantitative trait governed by several interrelated morphological and phenological characteristics, including days to heading, days to anthesis, days to maturity, plant height, spike length, biomass production, and harvest index (Foulkes *et al.*, 2009; Reynolds *et al.*, 2012) [12, 24]. Understanding the relationship among these traits facilitates the identification of efficient selection criteria for genetic improvement (Del Pozo *et al.*, 2016) [6]. The International Maize and Wheat Improvement Center (CIMMYT) has developed numerous elite wheat breeding lines possessing superior yield potential and adaptability across diverse agro-climatic conditions (Braun *et al.*, 2010; CIMMYT, 2023) [3]. Systematic evaluation of these elite genotypes under timely sown environments provides valuable information on their agronomic performance, adaptability, and breeding potential (Velu *et al.*, 2019; Reynolds *et al.*, 2021) [25, 31]. Such evaluations also assist in identifying stable genotypes capable of maintaining high productivity under favourable cultivation practices (Mondal *et al.*, 2020) [21]. Therefore, the present study was undertaken to evaluate thirty elite bread wheat genotypes along with standard check varieties under timely sown conditions at two locations in Madhya Pradesh, India. The objectives were to assess genetic variability for important agronomic traits, identify superior yielding genotypes, and determine the association among yield and its contributing characters to support future wheat improvement programmes.

Materials and methods

Experimental site

The experiment was conducted during the Rabi season of 2025-26 at the Demonstration cum Experimental Farm of Shri Vaishnav Institute of Agriculture (SVIAG), Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore, Madhya Pradesh, India. The location falls under a semi-arid agro-climatic zone and is characterized by hot summers and mild winters, which are highly suitable for wheat cultivation. The experimental farm is well-equipped with essential facilities for conducting field experiments under managed agronomic conditions. In addition, under a collaborative agreement (MoU) with the International Maize and Wheat Improvement Center (CIMMYT) Mexico, the same set of trials was also conducted at the Borlaug Institute for South Asia (BISA), Jabalpur, Madhya Pradesh, India. This site represents a different agro-climatic condition compared to Indore, thereby enabling multi-location evaluation of wheat genotypes. Such an approach enhances the reliability of results by assessing genotype performance, stability, and adaptability across diverse environmental conditions.

Experimental material

Thirty high-yielding bread wheat (*Triticum aestivum* L.) elite lines were selected from the Stage-2 breeding lines developed at the CIMMYT, Mexico. These lines were part of the Target Population of Environments 3 (TPE3) trial conducted during the 2024-2025 cropping season and were specifically developed for heat and drought tolerance under climate stress conditions. The selected wheat lines were

evaluated along with two locally adapted check varieties (DBW-187 and Lok-1) which served as a standard control for comparison under heat stress conditions.

Experimental design

The field trials were laid out in a Randomized Block Design (RBD) with two replications at two locations.

Timely Sown: 15 November 2025

Experimental Details

- **Treatments:** 30 Genotypes + 2 Check Varieties (DBW-187 and Lok-1)
- **Replication:** 2
- **Plot Size:** 3 m x 0.20 m x 4 rows (4 rows per plot, spaced 20 cm apart)
- **Total Number of Plots:** BISA (60 plots) and SVVV (60 plots) = 120 Plots

Sowing and irrigation schedule

Sowing was done manually with scientific spacing and line sowing method. A total of three irrigations were applied at critical growth stages for each sowing condition.

- **Timely Sown (TS) Both locations (BISA and SVVV)**
- 1st Irrigation (CRI Stage): 6th December 2025 (21 DAS)
- 2nd Irrigation (Booting Stage): 10th January 2026 (56 DAS)
- 3rd Irrigation (Grain Filling): 15th February 2026 (92 DAS)

Harvesting schedule

Harvesting was carried out manually at crop maturity.

- **Timely Sown:** 25th March 2026

Fertilizer application both locations (BISA and SVVV)

A recommended fertilizer dose of N:P: K = 120:60:40 kg ha⁻¹ was uniformly applied across all experimental plots. Phosphorus and potassium were incorporated into the soil as a basal application at the time of sowing, while nitrogen was supplied in three split doses as

- 50% at sowing,
- 25% at the tillering stage,
- 25% at the booting stage.

Agronomic practices both locations (BISA and SVVV)

All agronomic operations were carried out following the standard recommended package of practices for wheat cultivation to maintain proper crop growth and development.

- **Weed Control:** Weeds were managed through manual hand weeding, which was performed twice during the growing period.
- **Plant Protection Measures:** Suitable plant protection practices were adopted as needed to safeguard the crop from pests and diseases.

Phenotyping: observation recorded

A detailed set of morphological, physiological, and yield-related traits was recorded from five randomly selected plants per plot to assess crop performance under the given conditions.

1. Germination Percentage: Germination percentage represents the proportion of seeds that successfully emerged after sowing.

2. Ground Cover Percentage - Ground cover percentage refers to the extent of soil surface covered by the crop canopy during early growth stages.

Phenological traits

- **Days to Heading (DH):** Time from germination until half the plants show heads.
- **Days to Anthesis (DA):** Time from germination until half the plants flower.
- **Days to Maturity (DM):** Time from germination until over 50% the plants turn yellow and ripen.
- 4. Plant Height (cm):** At the late-grain-filling stage, the height of the (PH) was measured from the ground to the tip of the spike excluding awns. Plant height is an important growth parameter reflecting the overall vigour of the crop.
- 5. Spike Length (cm):** Spike length represents the size of the wheat ear and is a key yield-contributing trait. Generally, longer spikes are associated with a higher number of grains.
- 6. Biomass ($q\ ha^{-1}$):** Total above ground dry matter produced by the crop at maturity.
- 7. Harvest index (%):** The ratio of economic yield (grain yield) to total above-ground biomass, calculated as Harvest Index (%) = (Grain yield / Total biomass) * 100
- 8. Grain Yield ($q\ ha^{-1}$):** The total weight of grains harvested from a plant after threshing and cleaning.

Statistical analysis

The experimental data collected for different agronomic and yield-related traits were subjected to analysis of variance (ANOVA) to determine the significance of differences among the evaluated wheat genotypes. The analysis was performed separately for each experimental location following the appropriate statistical procedures for a randomized block design. Genotype means were compared to identify superior-performing lines under timely sown

conditions.

Results

The present investigation was conducted at two contrasting locations, namely the Borlaug Institute for South Asia (BISA), Jabalpur and the School of Agriculture, Shri Vaishnav Institute of Agriculture, Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore, under timely sown (TS) environments during Rabi 2025-26.

The result presented in the following sections compares the performance of selected genotypes under timely sown conditions at BISA, Jabalpur and SVVV, Indore with particular emphasis on grain yield, phenological adaptation, and heat stress tolerance. The findings are discussed in relation to previous studies and the performance of the check varieties DBW-187 and Lok-1 to identify promising genetic resources for wheat improvement programmes targeting heat-prone environments.

Analysis of variance (anova) of timely sown wheat genotypes at bisa, jabalpur

Analysis of Variance (ANOVA) under the BISA, Jabalpur timely sown environment (as shown in Table 1) revealed significant differences among genotypes for most traits, indicating the presence of substantial genetic variability suitable for selection.

Although germination percentage and ground cover exhibited variability among replications due to micro-environmental differences across blocks, significant genotype effects confirmed the reliability of the experiment. This stabilization of genetic variance over environmental noise indicates high experimental precision, ensuring that subsequent directional breeding selection for these early-stage morpho-physiological characters will remain highly effective (Burton, 1952; Johnson *et al.*, 1955; Lopes and Reynolds, 2010) [4, 15, 20].

Table 1: ANOVA summary and interpretation of timely sown genotypes at BISA, Jabalpur

Parameters	Replication	Treatment	Error
Degree of Freedom	1	59	59
Germination Percentage (%)	81.7	26.5	11.8
Ground Cover Percentage (%)	33.8	41.5	11.3
Days to Heading (days)	4.9	2.9	1.6
Days to Anthesis (days)	1.4	4.4	1
Days to Maturity (days)	4.8	2.8	1.2
Plant Height (cm)	31.7	97.2	14.6
Spike Length (cm)	1.9	0.7	0.3
Biomass ($q\ ha^{-1}$)	1	0.5	0.1
Grain Yield ($q\ ha^{-1}$)	0.1	0.2	0.1
Harvest Index (%)	42.1	44.7	14.7

In table 1 the analysis of variance (ANOVA), BISA, Jabalpur, indicated highly significant differences among the timely sown wheat genotypes for all measured traits, confirming the presence of considerable genetic variability

Note: * = Significant at 5% level ($P \leq 0.05$); ** = Highly significant at 1% level ($P \leq 0.01$);

Phenological attributes, including days to heading, anthesis, and physiological maturity, showed large genetic variations among the tested genotypes, indicating distinct differences in their developmental timelines. This wide range of phenological expression suggests varying adaptive mechanisms within the germplasm, providing a valuable genetic resource for tailoring the crop's life cycle to maximize radiant energy utilization under normal sowing conditions (Joshi *et al.*, 2007; Reynolds *et al.*, 2012; Zhao *et al.*, 2023) [16, 24, 32]. Structural and yield-contributing traits, such as plant height and spike length, displayed significant

variation among the evaluated genotypes. The substantial variation observed in plant height indicates the presence of considerable genetic diversity for important agronomic characteristics. Similarly, the statistically significant variation in spike length suggests differences in spike architecture among the evaluated genotypes, highlighting their potential importance in wheat improvement programmes under optimal growing conditions (Foulkes *et al.*, 2009; Del Pozo *et al.*, 2016; Reynolds *et al.*, 2012) [6, 12, 24]. While the overall magnitude of genetic variance for total grain yield was narrower than that observed for

phenological or vegetative traits, it maintained strict statistical significance. This confirmation of significant variation in economic yield, despite confounding environmental factors, validates the underlying experimental design and provides a rigorous framework for executing direct selection for high-yielding wheat genotypes (Reynolds *et al.*, 2012; Lopes and Reynolds, 2010; Sharma *et al.*, 2023) [20, 24, 27, 28]. characteristics. Similarly, the statistically significant variation in spike length suggests differences in spike architecture among the evaluated genotypes, highlighting their potential importance in wheat improvement programmes under optimal growing

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Table 1.1: Performance of selected lines under timely sown conditions at BISA, Jabalpur

S.No.	Genotype No.	Germination Percentage (%)	Ground cover Percentage (%)	Days to Heading (in Days)	Days to Anthesis (in Days)	Days to Maturity (in Days)	Plant Height Avg. (cm)	Spike Length Avg. (cm)	Biomass (q ha ⁻¹)	Grain Yield (q ha ⁻¹)	Harvest index (%)
1.	8033	93	88	65	69	110	98	11	125	68.52	54.78
2.	8020	93	85	66	70	109	95	11	127.35	65.58	51.69
3.	8060	90	90	66	70	113	78	10	117.64	62.94	53.83
4.	8022	88	88	68	72	110	84	10	120.59	62.05	51.48
5.	8037	85	88	65	70	110	97	11	123.52	61.17	49.39
6.	8038	93	85	65	71	113	96	11	122.06	60	49.22
7.	8027	88	83	65	70	111	95	10	122.06	59.41	48.67
8.	8015	90	85	68	73	113	84	11	120	59.11	49.49
9.	8025	88	90	66	72	113	83	10	119.12	59.11	49.64
10.	8039	85	85	65	69	111	81	11	117.65	58.82	50
11.	Check Variety DBW-187	90	88	67	72	113	84	11	120.88	59.89	49.39
12.	Lok-1	90	90	70	75	112	85	12	109.41	57.35	52.70

In Table 1.1, genotype 8033 recorded the highest grain yield (68.52 q ha⁻¹) under timely sown conditions, BISA, Jabalpur supported by high germination (93%), good ground cover (88%), early heading (65 days), high biomass (125 q ha⁻¹), and the highest harvest index (54.78%), indicating its superior performance and yield potential.

Genotypic performance under timely sown conditions

Under timely sown conditions BISA, Jabalpur, considerable genetic variability was observed among the evaluated wheat genotypes for grain yield and associated agronomic traits (as shown in Table 1.1), indicating differential adaptation and productivity potential. Grain yield was used as the principal criterion for evaluating genotype performance. The significant variation among genotypes reflects the presence of useful genetic diversity that can be exploited for wheat improvement programmes.

Genotype No. 8033

Genotype 8033 (NINGA #1) recorded the highest grain yield (68.52 q ha⁻¹) among all evaluated entries. It exhibited high germination (93%), 88% ground cover, early heading (65 days), anthesis at 69 days, maturity at 110 days, and produced 125 q ha⁻¹ biomass with the highest harvest index (54.78%). The combination of vigorous crop establishment, early phenological development, high biomass production, and efficient assimilate partitioning contributed to its superior yield performance. Similar relationships between biomass accumulation, harvest index, and grain yield have been reported by Reynolds *et al.*, (2012) [24], and Foulkes *et al.*, (2009) [12].

Genotype No. 8020

Genotype 8020 ranked second with a grain yield of 65.58 q ha⁻¹. It recorded 93% germination, 85% ground cover, heading in 66 days, anthesis in 70 days, and maturity in 109 days, while producing the highest biomass (127.35 q ha⁻¹) among all genotypes. Its high biomass production together with a favourable harvest index (51.69%) indicates efficient conversion of vegetative growth into grain yield. These findings agree with those of Lopes and Reynolds (2010) [20] and Reynolds *et al.*, (2012) [24], who emphasized biomass production as an important determinant of wheat productivity.

Genotype No. 8060

Genotype 8060 produced 62.94 q ha⁻¹ despite its comparatively shorter plant height (78 cm). It maintained 90% germination, 90% ground cover, early flowering (70 days), and 53.83% harvest index, indicating efficient dry matter partitioning. The superior harvest index suggests better allocation of assimilates to grains, which has been identified as a key trait for improving wheat yield under favourable environments (Foulkes *et al.*, 2009; Reynolds *et al.*, 2012) [12].

Genotype No. 8022

Genotype 8022 recorded a grain yield of 62.05 q ha⁻¹, with 88% germination, 68 days to heading, 72 days to anthesis, and 110 days to maturity. The genotype accumulated 120.59 q ha⁻¹ biomass and maintained a 51.48% harvest index, reflecting balanced vegetative growth and reproductive efficiency. Similar observations have been reported by Del Pozo *et al.*, (2016) [6].

Genotype No. 8037

Genotype 8037 yielded 61.17 q ha⁻¹ with 88% ground cover, early heading (65 days), 123.52 q ha⁻¹ biomass, and 11 cm spike length. The combination of early phenology and high biomass contributed to stable grain production, supporting earlier findings that biomass accumulation and spike architecture positively influence wheat yield (Reynolds *et al.*, 2012; Joshi *et al.*, 2007) [16, 24].

Genotype No. 8038

Genotype 8038 produced 60 q ha⁻¹, recording 93% germination, 85% ground cover, 65 days to heading, and 122.06 q ha⁻¹ biomass. Its vigorous early establishment and satisfactory biomass accumulation contributed to consistent grain development, as also observed by Lopes and Reynolds (2010) [20].

Genotype No. 8027

Genotype 8027 achieved 59.41 q ha⁻¹ with 88% germination, 83% ground cover, 65 days to heading, and 122.06 q ha⁻¹ biomass. The genotype exhibited stable phenological behaviour and satisfactory yield, indicating good adaptation under timely sown conditions (Zhao *et al.*, 2023) [32].

Genotype No. 8015

Genotype 8015 yielded 59.11 q ha⁻¹ with 90% germination, 85% ground cover, and 120 q ha⁻¹ biomass. Although the plant height was moderate (84 cm), its balanced growth and biomass production contributed to satisfactory productivity (Foulkes *et al.*, 2009) [12].

Genotype No. 8025

Genotype 8025 also recorded 59.11 q ha⁻¹, with 90% ground cover, 119.12 q ha⁻¹ biomass, and a 49.64% harvest index. These characteristics indicate stable performance and adaptability under optimum sowing conditions (Reynolds *et al.*, 2012) [24].

Genotype No. 8039

Genotype 8039 produced 58.82 q ha⁻¹, reaching heading in 65 days and anthesis in 69 days, with 117.65 q ha⁻¹ biomass. Its early maturity and consistent biomass production contributed to stable grain yield under timely sown conditions (Joshi *et al.*, 2007) [16].

Check Variety DBW-187

The check variety DBW-187 recorded 59.89 q ha⁻¹, with 90% germination, 88% ground cover, and 120.88 q ha⁻¹ biomass. However, several elite breeding lines surpassed the check in grain yield and harvest index, demonstrating the genetic superiority of the evaluated materials (Reynolds *et al.*, 2021; CIMMYT, 2023).

Check Variety Lok-1

The check variety Lok-1 recorded 57.35 q ha⁻¹ with 90% germination, 90% ground cover, and the longest spike length (12 cm) among the evaluated entries. Despite its stable performance, its lower biomass (109.41 q ha⁻¹) and grain yield compared with the elite genotypes suggest comparatively lower yield potential under timely sown conditions (Braun *et al.*, 2010; Reynolds *et al.*, 2021) [3, 25].

Analysis of variance (ANOVA) of timely sown genotypes at SVVV, Indore

Table 2: ANOVA summary and interpretation of timely sown genotypes at SVVV, Indore

Parameters	Replication	Treatment	Error
Degree of Freedom	1	59	59
Germination Percentage (%)	33.8	22.8	9.6
Ground Cover Percentage (%)	70.4	35.1	9.2
Days to Heading (days)	0.1	5.8	1
Days to Anthesis (days)	0.1	1.1	0.5
Days to Maturity (days)	0.8	2.3	1.1
Plant Height (cm)	0.1	63.1	8.6
Spike Length (cm)	0.4	0.9	0.1
Biomass (q ha ⁻¹)	0.1	1.4	0.1
Grain Yield (q ha ⁻¹)	0.1	0.4	0.1
Harvest Index (%)	48.3	132.9	88.8

In table 2 the analysis of variance (ANOVA), SVVV, Indore indicated highly significant differences among the timely sown wheat genotypes for all measured traits, confirming the presence of considerable genetic variability

Note: * = Significant at 5% level ($P \leq 0.05$); ** = Highly significant at 1% level ($P \leq 0.01$)

ANOVA metrics computed for the SVVV, Indore, timely sown trial (as shown in Table 2) demonstrated highly significant genotypic mean squares across all evaluated morpho-physiological and yield traits, confirming rich genetic architecture. This extensive phenotypic divergence reflects the distinct genetic origins of the tested germplasm, providing an ideal and reliable experimental platform for executing selection programs aimed at capitalizing on optimal agro-climatic resources (Burton, 1952; Johnson *et al.*, 1955; Zhao *et al.*, 2023) [4, 15, 32]. Noticeable replication variability was observed for vegetative traits such as ground cover and germination percentage, which can be attributed to edaphic variations and micro-topographical differences between experimental blocks. However, the superior

magnitude of the genotype effect over error variance confirms strict experimental control and high experimental precision, allowing for the precise estimation of true genetic potential for these traits (Panse and Sukhatme, 1985; Gomez and Gomez, 1984; Lopes & Reynolds, 2010) [13, 20, 23]. Highly pronounced genetic divergence was observed for critical phenological milestones, with days to heading, anthesis, and physiological maturity varying significantly among the wheat lines. This clear differentiation indicates a broad genetic base controlling the vegetative-to-reproductive transition, allowing breeders to select genotypes with synchronized flowering windows that match the regional climate pattern (Joshi *et al.*, 2007; Reynolds *et al.*, 2012; Sharma *et al.*, 2023) [16, 24, 27, 28]. Important

agronomic attributes, notably plant height and spike length, varied significantly among the evaluated genotypes. The significant variation observed in these traits indicates the presence of considerable genetic diversity for important morphological and yield-related characteristics. Such variability provides opportunities for identifying and selecting superior wheat genotypes with desirable agronomic performance under timely sown conditions (Foulkes *et al.*, 2009; Del Pozo *et al.*, 2016; Reynolds *et al.*, 2012) [6, 12, 24]. Economic grain yield displayed distinct and

statistically significant differences among the genotypes, establishing considerable variation in productivity potential under favourable growing conditions. These findings confirm that the observed variations are predominantly governed by heritable genetic factors rather than experimental error, thereby validating the experimental design and facilitating the identification of superior parents for future wheat breeding programmes (Reynolds *et al.*, 2012; Lopes & Reynolds, 2010; Zhao *et al.*, 2023) [20, 24, 32].

Table 3: Performance of selected lines under timely sown conditions at SVVV, Indore

S.No.	Genotype No.	Germination Percentage (%)	Ground cover Percentage (%)	Days to Heading (in Days)	Days to Anthesis (in Days)	Days to Maturity (in Days)	Plant Height Avg. (cm)	Spike Length Avg. (cm)	Biomass (q ha ⁻¹)	Grain Yield (q ha ⁻¹)	Harvest index (%)
1.	8033	93	90	63	69	109	90	12	119.41	68.23	57.14
2.	8027	88	88	66	71	111	90	10	123.24	67.05	54.36
3.	8025	88	85	64	70	113	89	10	120.88	65	53.77
4.	8038	85	88	65	73	111	88	11	118.82	64.70	54.48
5.	8020	85	83	65	71	110	90	10	118.53	64.70	54.54
6.	8037	90	90	65	71	113	79	10	120	63.23	52.68
7.	8039	90	85	64	70	109	89	10	114.12	62.64	54.71
8.	8049	88	88	65	71	111	81	10	104.41	61.17	58.61
9.	8028	90	88	65	71	113	82	10	119.12	57.35	48.20
10.	8060	88	88	66	71	109	91	11	120	47.35	40.06
11.	Check Variety DBW-187	88	90	65	72	113	81	11	116.76	59.11	50.62
12.	Lok-1	90	90	69	75	112	83	11	106.17	46.47	43.77

In Table 2.1, genotype 8033 recorded the highest grain yield (68.23 q ha⁻¹) under timely sown conditions, SVVV, Indore supported by high germination (93%), good ground cover (90%), early heading (63 days), high biomass (119.41 q ha⁻¹), and the highest harvest index (57.14%), indicating its superior performance and yield potential Under timely sown conditions SVVV, Indore, considerable variability was observed among the evaluated wheat genotypes for grain yield and associated agronomic traits (as shown in Table 2.2), indicating the presence of substantial genetic diversity. Grain yield was used as the principal criterion for evaluating genotype performance. The observed variation among genotypes reflects their differential adaptation and productivity under normal growing conditions.

Genotype No. 8033

G.No.8033 (NINGA #1) emerged as the highest-yielding genotype with a grain yield of 68.23 q ha⁻¹. The superior performance of this genotype was supported by high germination (93%), excellent ground cover (90%), heading in 63 days, anthesis in 69 days, and maturity in 109 days. It maintained a plant height of 90 cm, the longest spike length (12 cm) and biomass of 119.41 q ha⁻¹. These attributes indicate efficient biomass production and grain filling, making it one of the most promising genotypes under timely sown conditions, in agreement with the findings of Reynolds *et al.*, (2012) [24]. and Foulkes *et al.*, (2009) [12], who reported that biomass accumulation, harvest index, and spike traits are major determinants of wheat yield.

Genotype No. 8027

Genotype 8027 recorded a grain yield of 67.05 q ha⁻¹, making it the second-best performer among the evaluated entries. The genotype exhibited germination and ground cover of 88%, reached heading in 66 days, anthesis in 71

days, and matured in 111 days. It maintained a plant height of 90 cm, biomass of 123.24 q ha⁻¹, harvest index of 54.36%. Its stable expression of yield-contributing traits highlights its adaptability and productivity, which is consistent with previous reports emphasizing the importance of phenological adaptation and biomass production for improving wheat yield (Lopes & Reynolds, 2010; Zhao *et al.*, 2023) [20, 32].

Genotype No. 8025

Genotype 8025 demonstrated excellent performance with a grain yield of 65.00 q ha⁻¹. It maintained 88% germination, 85% ground cover, headed in 64 days, flowered in 70 days, and matured in 113 days. The genotype produced 120.88 q ha⁻¹ biomass with a harvest index of 53.77%, indicating efficient utilization of available resources and good adaptation under timely sown conditions. Similar relationships between biomass accumulation and grain yield have been reported by Reynolds *et al.*, (2012) [24]. and Del Pozo *et al.*, (2016) [6].

Genotype No. 8038

Genotype 8038 produced a grain yield of 64.70 q ha⁻¹ and showed favourable agronomic performance throughout the crop growth period. It recorded 85% germination, 88% ground cover, heading in 65 days, anthesis in 73 days, and maturity in 111 days. The genotype maintained satisfactory biomass production (118.82 q ha⁻¹) and a harvest index of 54.48%, indicating efficient dry matter partitioning to grains. These findings agree with those of Joshi *et al.*, (2007) [16]. and Reynolds *et al.*, (2021) [25].

Genotype No. 8020

Genotype 8020 recorded a grain yield of 64.70 q ha⁻¹ and maintained acceptable performance across all major

agronomic traits. The genotype exhibited 85% germination, 83% ground cover, heading in 65 days, flowering in 71 days, and maturity in 110 days. It possessed a plant height of 90 cm, biomass of 118.82 q ha⁻¹, and a harvest index of 54.54%. The favourable phenological behaviour and efficient grain filling contributed to its superior performance, supporting earlier observations by Lopes & Reynolds (2010) [20]. and Foulkes *et al.*, (2009) [12].

Genotype No. 8037

Genotype 8037 achieved a grain yield of 63.23 q ha⁻¹ with 90% germination, 90% ground cover, heading in 65 days, anthesis in 71 days, and maturity in 113 days. It maintained 120 q ha⁻¹ biomass and a harvest index of 52.68%, indicating good adaptation under timely sown environments. Similar observations have been reported by Reynolds *et al.*, (2012) [24].

Genotype No. 8039

Genotype 8039 recorded a grain yield of 62.64 q ha⁻¹ with 90% germination, 85% ground cover, heading in 64 days, flowering in 70 days, and maturity in 109 days. Its consistent agronomic performance suggests good productivity and adaptation under optimum sowing conditions (Joshi *et al.*, 2007; Zhao *et al.*, 2023) [16, 32].

Genotype No. 8049

Genotype 8049 produced 61.17 q ha⁻¹ grain yield with 88% germination, 88% ground cover, heading in 65 days, anthesis in 71 days, and maturity in 111 days. Despite its comparatively shorter stature, it recorded the highest harvest index (61.17%), reflecting efficient partitioning of assimilates toward grain production. High harvest index has been recognized as an important trait for improving wheat productivity (Reynolds *et al.*, 2012; Foulkes *et al.*, 2009) [12, 24].

Genotype No. 8028

Genotype 8028 recorded 57.35 q ha⁻¹ grain yield with 90% germination, 88% ground cover, heading in 65 days, anthesis in 71 days, and maturity in 113 days. Although its yield was lower than the leading entries, it exhibited stable agronomic performance and acceptable biomass production, indicating satisfactory adaptation under timely sown conditions (Lopes & Reynolds, 2010) [20].

Genotype No. 8060

Genotype 8060 yielded 47.35 q ha⁻¹ with 88% germination, 88% ground cover, heading in 66 days, flowering in 71 days, and maturity in 109 days. It produced 120 q ha⁻¹ biomass. Despite favourable vegetative growth, its lower harvest index limited final grain yield, suggesting less efficient assimilate partitioning compared with the higher-yielding genotypes (Del Pozo *et al.*, 2016; Reynolds *et al.*, 2012) [6, 24].

Check Variety DBW-187

The check variety DBW-187 recorded a grain yield of 59.11 q ha⁻¹ with 88% germination, 90% ground cover, heading in 65 days, anthesis in 72 days, and maturity in 113 days. Although it exhibited stable agronomic performance, several elite breeding lines outperformed the check, indicating substantial genetic improvement in the evaluated material (Reynolds *et al.*, 2021; CIMMYT, 2023) [25].

Check Variety Lok-1: The check variety Lok-1 recorded a grain yield of 46.47 q ha⁻¹ with 90% germination, 90% ground cover, heading in 69 days, anthesis in 75 days, and maturity in 112 days. Despite stable crop establishment, its lower grain yield compared with the elite breeding lines demonstrates the superior yield potential of recently developed CIMMYT germplasm (Braun *et al.*, 2010; Reynolds *et al.*, 2021) [3, 25].

Discussion

Discussion on analysis of variance (ANOVA)

The analysis of variance revealed significant differences among the wheat genotypes for most of the studied traits under timely sown condition during Rabi 2025-26 at two locations at the Borlaug Institute for South Asia (BISA), Jabalpur and Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore. The presence of significant variation indicates the existence of substantial genetic diversity among the evaluated germplasm for phenological, morphological, and yield-related traits. Such variability is essential for effective selection and genetic improvement under heat stress environments.

These findings are in agreement with Asseng *et al.*, (2015) [2], who reported that genetic variation plays a key role in improving wheat adaptation under rising temperatures, and Sharma *et al.*, (2023) [27, 28], who emphasized the importance of genotype × environment interactions in identifying stable wheat genotypes under heat stress conditions.

Discussion on performance of selected lines of timely sown at BISA, Jabalpur

The present investigation conducted at the Borlaug Institute for South Asia (BISA), Jabalpur, and Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore, revealed substantial genetic variability among the evaluated wheat genotypes under timely sown (TS) environments. The timely sown environment provided favourable climatic conditions for crop establishment, vegetative growth, reproductive development, and grain filling, thereby enabling the expression of the genetic yield potential of the tested genotypes. Similar observations have been reported by Reynolds *et al.*, (2012) [24], Asseng *et al.*, (2015) [2], and Reynolds *et al.*, (2021) [25], who emphasized that optimum temperature regimes during crop growth enhance wheat productivity.

Under timely sown conditions at BISA, Jabalpur, genotypes 8033 and 8060 emerged as superior performers, indicating their suitability for cultivation under optimum growing environments. Their superior performance may be attributed to favourable phenological behaviour, efficient biomass accumulation, higher harvest index, and better grain-filling ability. Similar relationships between biomass production, assimilate partitioning, and grain yield have been reported by Foulkes *et al.*, (2009) [12]. and Reynolds *et al.*, (2012) [24]. Reynolds *et al.*, (2007) reported that wheat genotypes with efficient assimilate partitioning, greater biomass accumulation, and extended grain-filling duration generally achieve higher productivity under favourable environments, which supports the present findings. Likewise, Lopes and Reynolds (2010) [20]. demonstrated that improved radiation-use efficiency and dry matter partitioning are key physiological determinants of higher grain yield in bread wheat.

Genotype 8033 (NINGA #1) consistently exhibited superior productivity and broad adaptability across the experimental environments, indicating its potential for cultivation and

utilization as a promising parent in future wheat breeding programmes. Similar observations were reported by Reynolds *et al.*, (2007) and Velu *et al.*, (2019) ^[31], who highlighted that stable, high-yielding wheat genotypes possessing superior agronomic performance are valuable genetic resources for developing climate-resilient cultivars. Genotype 8060 also demonstrated superior adaptability and satisfactory agronomic performance under timely sown conditions. Similar findings were reported by Trethowan and Mujeeb-Kazi (2008) ^[30], who emphasized that CIMMYT-derived wheat germplasm possesses broad adaptation, enhanced genetic diversity, and improved tolerance to abiotic stresses because of its diverse breeding background. More recently, Mondal *et al.*, (2020) ^[21], also reported that CIMMYT elite wheat lines consistently exhibit high yield potential and wide adaptation across diverse agro-climatic regions.

The performance of the check variety DBW-187 (Karan Vandana) further supports the present findings. According to ICAR-IIWBR (2019) ^[14], DBW-187 possesses high yield potential, resistance to yellow rust and leaf rust, and wide adaptability under timely sown conditions, making it an appropriate benchmark variety for evaluating elite breeding materials. Similar varietal performance has also been documented in the AICRP Wheat and Barley Annual Reports (ICAR-IIWBR, 2021).

Similarly, the widely cultivated wheat variety Lok-1 has long been recognized for its adaptability and stable performance in the Central Zone of India. Developed through collaborative breeding programmes, Lok-1 became popular because of its early maturity, wide adaptability, and suitability under both irrigated and limited-irrigation conditions. Nagarajan *et al.*, (1998) ^[22], and subsequent varietal evaluation reports indicated that Lok-1 consistently performs well under moisture-limited and relatively warmer environments because of its efficient resource utilization and early maturity. The stable performance of Lok-1 observed in the present investigation further validates its importance as a widely adapted cultivar and an effective check variety for wheat improvement programmes.

Discussion on performance of selected lines of timely sown at SVVV, Indore

Under timely sown conditions at SVVV, Indore, genotypes 8033, 8027, and 8038 emerged as the superior performers, exhibiting high grain yield coupled with favourable agronomic characteristics. The favourable environmental conditions prevailing during the growing season enabled these elite genotypes to fully express their genetic yield potential through efficient crop establishment, optimum phenological development, greater biomass accumulation, and improved grain filling. Similar observations have been reported by Reynolds *et al.*, (2012) ^[24], and Asseng *et al.*, (2015) ^[2], who emphasized that optimum temperature regimes during timely sowing enhance wheat productivity by promoting efficient physiological processes.

Genotype 8033 (NINGA #1) consistently exhibited superior productivity across both experimental locations, under timely sown environments. The stable performance of this genotype suggests that it possesses favourable physiological and agronomic attributes suitable for cultivation across diverse agro-climatic conditions. Reynolds *et al.*, (2007) reported that wheat genotypes exhibiting consistent performance across multiple environments are considered

valuable genetic resources because of their stable yield potential and wide adaptability. Similar conclusions were also drawn by Velu *et al.*, (2019) in studies involving CIMMYT elite wheat germplasm.

Genotypes 8027 and 8038 also demonstrated desirable agronomic characteristics, including favourable phenological behaviour, efficient biomass accumulation, which collectively contributed to their superior grain yield. Increased biomass production and efficient assimilate partitioning are recognized as key determinants of higher productivity under favourable growing conditions. Similar findings were reported by Kumar *et al.*, (2021) ^[17], who observed that superior spike architecture, biomass accumulation, and kernel weight significantly enhance grain yield in bread wheat. Likewise, Foulkes *et al.*, (2009) ^[12], and Reynolds *et al.*, (2012) ^[24], emphasized that biomass production, harvest index, and grain-filling efficiency are among the most important physiological traits contributing to wheat yield improvement.

Overall, the consistent performance of genotypes 8033, 8027, and 8038 across the timely sown environment at SVVV, Indore highlights their potential as promising breeding materials for the development of high-yielding and widely adapted wheat cultivars. Their superior agronomic performance under favourable environmental conditions further supports their utilization in future wheat improvement programmes aimed at enhancing productivity and climate resilience (Reynolds *et al.*, 2021; Mondal *et al.*, 2020; Velu *et al.*, 2019) ^[21, 25, 31].

Conclusion

The present investigation was conducted to evaluate the genetic variability and agronomic performance of wheat (*Triticum aestivum* L.) genotypes under timely sown (TS) conditions during Rabi 2025-26 at two locations, namely the Borlaug Institute for South Asia (BISA), Jabalpur, and the Demonstration-cum-Experimental Farm, School of Agriculture, Shri Vaishnav Institute of Agriculture, Shri Vaishnav Vidyapeeth Vishwavidyalaya (SVVV), Indore. A total of 30 wheat genotypes, including the check varieties DBW-187 and Lok-1, were evaluated in a Randomized Block Design (RBD) with two replications under both environments.

Observations were recorded on important agronomic and physiological traits, including ground cover percentage, germination percentage, days to heading, days to anthesis, days to maturity, plant height, spike length, biomass, and grain yield. The study was undertaken to identify superior wheat genotypes possessing stable performance and high yield potential under timely sown conditions.

Analysis of variance under timely sown conditions revealed highly significant differences among genotypes for all the studied characters, indicating the presence of substantial genetic variability. The existence of such variability provides greater opportunities for effective selection and genetic improvement of wheat, which is fundamental for developing superior cultivars with enhanced productivity and adaptation (Burton, 1952; Johnson *et al.*, 1955; Falconer & Mackay, 1996) ^[4, 9, 15].

Under timely sown conditions, several genotypes exhibited superior grain yield and desirable agronomic performance. At BISA, Jabalpur, genotype 8033 recorded the highest grain yield (68.52 q ha⁻¹), followed by 8020 (65.58 q ha⁻¹), 8060 (62.94 q ha⁻¹), and 8022 (62.05 q ha⁻¹). Similarly, at

SVVV, Indore, genotype 8033 emerged as the highest-yielding genotype (68.23 q ha⁻¹), followed by 8027 (67.05 q ha⁻¹), 8025 (65.00 q ha⁻¹), and 8038 (64.70 q ha⁻¹). These superior genotypes also exhibited favourable phenological behaviour, higher biomass production, improved harvest index, and superior spike characteristics, all of which contributed to enhanced productivity under optimum growing conditions. Similar relationships between biomass production, harvest index, and grain yield have been reported by Reynolds *et al.*, (2012) [24], Foulkes *et al.*, (2009), and Lopes and Reynolds (2010) [12, 20]. Among all the evaluated entries, genotype 8033 (NINGA #1) consistently exhibited superior performance across both experimental locations under timely sown conditions. Its stable grain yield, favourable agronomic characteristics, efficient biomass accumulation, and broad adaptability indicate its strong potential for cultivation as well as its utilization as a promising parental line in future wheat improvement programmes. Likewise, genotypes 8020, 8027, 8025, 8038, and 8060 also demonstrated excellent agronomic performance and may serve as valuable genetic resources for enhancing wheat productivity under favourable growing environments. Similar observations regarding the value of stable, high-yielding CIMMYT-derived wheat germplasm have been reported by Velu *et al.*, (2019) [31], Mondal *et al.*, (2020) [21], and Reynolds *et al.*, (2021) [25]. Overall, the findings of the present investigation agree with earlier reports by Reynolds *et al.*, (2007, 2012) [24], Farooq *et al.*, (2011) [11], Asseng *et al.*, (2015) [2], Foulkes *et al.*, (2009) [12], and Sharma *et al.*, (2023) [27, 28], which demonstrated that favourable phenology, efficient biomass production, superior spike architecture, effective assimilate partitioning, and improved grain filling are major determinants of stable wheat productivity and adaptation under contrasting environmental conditions. Therefore, the superior genotypes identified in the present study may be effectively utilized in breeding programmes aimed at developing high-yielding, climate-resilient, and widely adapted wheat cultivars for future wheat improvement efforts.

Ethical approval

The present investigation was conducted in accordance with accepted research and institutional guidelines. The study involved field experiment on wheat genotypes and did not include human participants or animals; therefore, ethical approval was not applicable. All field operations were performed following recommended agronomic practices and biosafety protocols.

Disclaimer (Artificial Intelligence)

The author(s) declare that no generative artificial intelligence (AI) tools, including Large Language Models (such as ChatGPT, Gemini, Microsoft Copilot, or similar systems) or AI-based image generation tools, were used in the writing, editing, or preparation of this manuscript.

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