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Evaluation of wheat genotypes for heat tolerance in late sown condition of Nepal

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Abstract

To study the effect of higher temperature on the yield of wheat (*Triticum aestivum* L.) genotypes, two field experiments (normal and late sown condition) were conducted from November 2021 to April 2022 at the Research farm of Rampur campus, Khairahani, Chitwan, Nepal. Twelve wheat genotypes were experimented in alpha lattice design with 3 replications. Observations for days to heading, days to maturity, plant height, grain filling period, thousand kernel weight, and grain yield were recorded, and analysis was done at 0.05 probability level. The performance of grain yield and other studied traits were significantly ($p \leq 0.05$) higher in the normal season compared to the late season. Highly significant effects ($p \leq 0.001$) of genotypes, season, and genotype by season interaction on grain yield and other traits were obtained. Genotype MYT1718-24 was one of the top grain yielding genotypes in both the environmental condition, while genotypes MYT1718-06, MYT1617-22172 were high yielding genotypes in late sown condition and MYT1819-08, MYT1819-19 were high yielding genotypes in normal season. The relative heat tolerance of the genotypes ranged from -13.99% to -57.64%. The genetic variability found in germplasms is adequate for developing heat-tolerant wheat varieties.

Key Words: *Correlation, Heat stress, Late season, Variability, Wheat*

Introduction

Wheat (*Triticum aestivum*) is the world's most crucial cereal crop, widely cultivated across the globe. It serves as a staple food in over 40 countries, supplying 82% of essential calories and 85% of the population's protein intake (Pandey et al., 2019). The global population is projected to reach 9.8 billion by 2050, with food demand expected to rise by 50-80%. Therefore, a significant increase in wheat yield will be necessary to ensure global food security (Collins & Chenu, 2021; Elferink & Schierhorn, 2016; UN, 2019). At the same time climate change is affecting the average weather pattern. Wheat growing areas lie from tropical to subtropical regions experiencing lots of stress due to climate change. Furthermore, the constantly shifting climate presents significant obstacles to maintaining the sustainability of worldwide wheat cultivation and production (Hasan et al., 2019). The major environmental stresses impacting wheat growth and development include cold, salinity, heat, and drought, all of which significantly reduce its yield potential. However, water scarcity and high temperatures are recognized as the leading environmental factors contributing to the global decline in wheat yields (Lesk et al., 2016; Liu et al., 2016). Wheat crops typically require temperatures between 12–22°C during most of their growth stages, especially during flowering and grain filling. Heat stress is one of the primary challenges to maintaining sustainable wheat production. Heat stress is described as an increase in temperature above a certain limit for a duration long enough to result in permanent harm to plant growth and development. It can lead to the partial or complete disruption of the crop's structure, form, biochemistry, and physiological processes. Heat stress from high temperatures occurs when the air temperature exceeds a critical threshold for an extended period, leading to injury or permanent damage to crop plants. Over 7 million hectares of wheat across approximately 50 countries are consistently affected by high temperatures. When temperatures rise above the optimal range, plants experience reduced nutrient absorption and photosynthetic efficiency. Additionally, the duration for organ growth (such as leaves, tillers, and spikes) shortens at different stages of wheat development. The continuous rise in global temperatures poses a threat to wheat production, with projections indicating an increase of 2°C–5°C by the year 2050 (Cheng et al., 2021). High temperature stress affects the wheat crop in each and every stage of the crop cycle (Farooq et al., 2011; Hunt, 2017). However, the impact of high temperature stress varies across different phenological stages, with its effects being more pronounced during reproductive development, also known as terminal heat stress, compared to vegetative growth (Yadav et al., 2022). Heat stress significantly reduces both the number and size of wheat leaves, causing the plant to remain in its vegetative stage for an extended period. Additionally, heat stress during the reproductive phase negatively impacts chloroplast function, which diminishes the activity of the plant's source organs and decreases its sink capacity. This leads to lower yields and early leaf senescence, reducing the green leaf area during reproduction. An elevation in temperature during the grain filling period results in a shortened grain filling duration, directly influencing both grain number and yield (Djanaguiraman et al., 2020). Previous research has suggested that for every degree Celsius increase in temperature between 18°C and 22°C, there is a 5% reduction in grain filling duration and a 3-4% reduction in yield, respectively. Based on these estimates, losses of up to 50% in yield potential have been projected when exposed to temperatures ranging from 32°C to 38°C during the critical grain formation period (Garg et al., 2013). To mitigate the adverse impact of high temperature stress, it is imperative to comprehend the heat tolerance mechanisms during crucial growth stages, with the aim of cultivating heat-resilient wheat varieties (Ali et al., 2020). While conventional breeding methods have led to the development of some heat-tolerant varieties suitable for various agroclimatic zones, the molecular, physiological, and genetic foundations of heat tolerance remain largely unidentified (Driedonks et al., 2016). Examining genotype reactions under heat stress conditions can aid in unraveling the mechanisms underlying heat tolerance mechanisms. Thus, the research objective was to explore the genetic variation present in twelve elite wheat genotypes at normal and late sown (heat stress) environmental conditions for identifying heat-tolerant genotypes.

Materials and Methods

Two field trials, one in the normal season and the other in the late season, were conducted at the research farm of Rampur Campus, Khairahani Chitwan, Nepal at 165 masl. The normal season was from November 2021 to March 2022 and the late season was from January 2021 to April 2022. Both experiments were conducted using an Alpha lattice design, with three replications. Each replication consisted of 4 blocks, and each block contained 3 plots. Each plot measured 3 m * 2 m (6 m^2). The row spacing was 25 cm, with 8 rows, each 3 meters long, maintained in each plot. Genotypes used in this trial were Bandganga, MYT1617-22, MYT1718-06, MYT1718-14, MYT1718-16, MYT1718-17, MYT1718-24, MYT1819-08, MYT1819-19, MYT1819-40, MYT1819-42 and Vijay. During the crop growing period, standard agronomic practices were applied. Six economically significant quantitative traits plant height, thousand-kernel weight, heading days, grain filling period, maturity days, and grain yield were measured across 12 wheat genotypes. The experimental data were processed using Microsoft Excel 2019, and analysis of variance (ANOVA) was performed using R.

Relative heat tolerance= $\frac{Yh - Yc}{Yc}/100\%$ Haque et al. (2009),

Where,
Yh is grain yield in late sown condition (heat stress),
Yc is grain yield in normal season condition.
Pearson's correlation coefficients of the parameters studied were obtained using SPSS version 16 software (SPSS, Chicago, Illinois, USA).

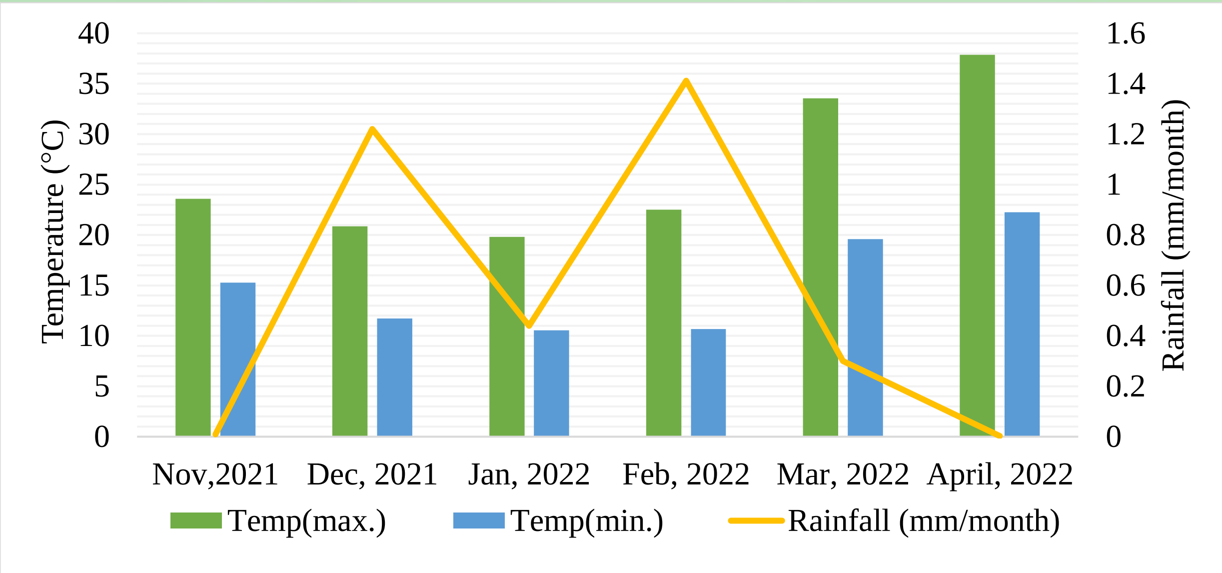

Figure 1: Mean monthly maximum, minimum temperature and Precipitation during wheat growing period (2021–2022)

Result and discussion

The findings in Table 1 revealed a significant variation among wheat genotypes, indicating that their yield performance differed at a 95% significance level (Rehman et al., 2021), showing that the genotypes responded differently under both conditions.

Table 1. Analysis of variance for grain yield under normal and heat stress conditions of 12 wheat genotypes in Chitwan

Source of variation	df	Mean squares	
		Normal condition	Stress condition
Replication	2	98372	818533
Genotypes	11	1395211***	2473797***
Block*Replication	9	137637	268413
Residual	13	242195	260165

Significant traits are denoted by * for p < .05, ** for p < .01, and *** for p < .001.

These results highlighted significant variation among genotypes, enabling the selection of superior genotypes for heat stress conditions. The maximum grain yield was observed in MYT1718-24 (5410.22 g) per ha followed by MYT1718-06 (5128.77 g) in stressed condition and MYT1819-19 (7346.17 g) and MYT1819-40 (7090.49 g) was highest grain yielding genotype under normal condition. The mean grain yield is reduced by 36.76% under heat stress condition. In the lab research conducted at Bangladesh by Karim et al. (2020) also reported loss of grain yield by 3-49% due to heat stress in wheat. Temperature acceleration during the period in wheat between the beginning of spike ignition and flowering appears to be the primary cause of the decrease in sink size, resulting in poor grain yield (Mirosavljević et al., 2021). Additionally, heat stress leads to a reduction in the duration of the grain filling phase, the number of tillers, and the number of spikelets per spike (Mirosavljević et al., 2021; Qin et al., 2008).
The performance of wheat genotypes exhibited significantly higher levels during the normal season compared to the late season, aligning with findings from various researchers regarding the detrimental effects of heat stress on wheat. According to Rehman et al. (2021), higher temperatures led to a notable decrease in the number of days required for booting, heading, flowering, and maturity. Additionally, exposure to elevated temperatures can substantially diminish grain yield (GY) (Fernie et al., 2022). The increased temperatures observed during the late season, as reported in meteorological data, had a pronounced impact on heat stress (Puri et al., 2015).

Effects of genotype, season, and genotype by season interaction on the germplasm
Table 2 revealed that the effects (mean squares) of genotype (G), season (S), and genotype by season interaction (G×S) on maturity days, plant height, and grain yield were consistently highly significant ($p \leq 0.001$). The impact of season (S) consistently surpassed that of genotype (G) and the genotype by season interaction (G×S) for each trait. Additionally, the effect of G was generally greater than that of G×S, except for plant height (G = 39 and G×S = 54) and grain yield (G = 1.39 and G×S = 2.33).

Table 2. Analysis of variance of agronomic traits of 12 wheat genotypes as influenced by late season and normal season in Chitwan

Traits	NG	Rep	Season	MSG	MSS	MS(G*S)	MSR	CV
DTH	12	3	2	13.6***	1081.1***	1.3	2	1.50%
DTM	12	3	2	3***	5339***	1***	1	0.95%
GFP	12	3	2	10.6***	1530.9***	1.3	1.6	3.36
PH	12	3	2	39***	21439***	54***	5	2.35%
TKW	12	3	2	103.97***	220.67***	34.72*	17.11	9.08%
GY	12	3	2	1.39***	96.95***	2.33***	0.53	9.50%

Significant traits are denoted by * for p < .05, ** for p < .01, and *** for p < .001. DTH = Days to heading, DTM = Days to maturity, GPF= Grain filling period, PH= Plant height, TKW= Thousand kernel weight, GY= Grain yield

The significant effects of G, E, and G×E obtained agree with the results of (Okechukwu et al., 2016; Khazratkulova et al., 2015). Most of the observed changes in the wheat germplasm are primarily due to seasonal (environmental) influences, as evidenced by the significantly stronger effect of season on all parameters compared to the effects of genotype and genotype by season interaction. Wan et al. (2022) explained that wheat grain yield (GY) is heavily influenced by production environments. Moreover, the significant genotypic effect on GY and other parameters suggests that there is sufficient genetic variation among wheat germplasms to be utilized in breeding programs for heat tolerance (Okechukwu et al., 2016).

Relative heat tolerance (RHT) of wheat germplasm
Figure 2 depicted the plasticity/stability of grain yield among genotypes in late seasons (heat-stressed environments) relative to their performance in corresponding normal seasons (control/heat-favorable environments). In Figure 1 (late season 1 *vs*. normal season 1), the RHT ranged from -13.99% in genotype MYT1718-24 to -57.64% in genotype MYT1819-40. MYT1718-24, MYT1617-22, MYT1718-17 are most resistant genotypes with relative heat tolerance 13.99, 17.21, 17.31 respectively while most susceptible genotypes for relative heat tolerance are MYT1819-08, MYT1819-19, MYT1819-40 with values -42.77%, -44.90%, -57.64% respectively.

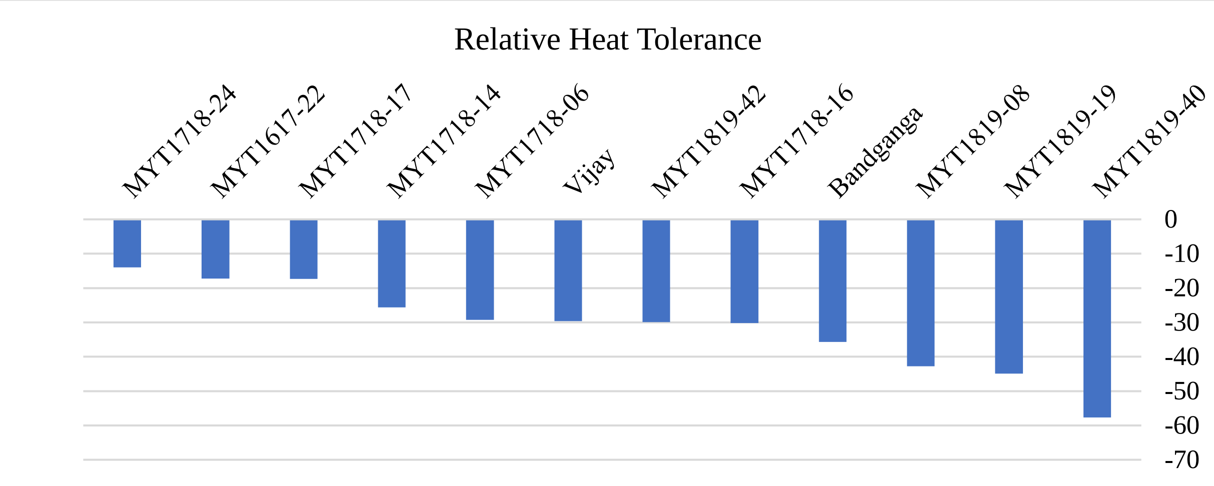

Figure 2: Relative Heat tolerance of twelve wheat genotypes in Chitwan

The relative heat tolerance graph (Figure 2) shows that the percentage of grain loss due to high temperatures experienced in the late season, compared to the normal season, ranged from 33.69% to 77.95% (Karim et al., 2020) . Okechukwu et al. (2016) previously reported that wheat planted in the late season experienced severe yield losses exceeding 50%. Consistently, the genotypes MYT1718-24, MYT1617-22, and MYT1718-17 showed relative heat tolerance (RHT) of less than 20%. These genotypes could serve as genetic sources for heat tolerance breeding programs, with MYT1718-24 standing out as the highest-yielding genotype in the late season.

Association of the grain yield and other parameters

In both normal and late sown condition grain yield has only significant correlation with grain filling period. Days to heading (DTH) negatively correlated with grain yield (GY) in both late and normal season (Table 3). Days to maturity have negative correlation with grain yield in late season while it has positive correlation in normal season. The grain filling period has a significant positive correlation with grain yield in both conditions. Plant height has a positive correlation with grain yield in normal condition whereas it has negative correlation with grain yield in late sown condition. Thousand kernel weight has negative correlation with grain yield in both conditions.

Table 3. Pearson correlation of grain yield and other studied traits of wheat germplasm in normal condition (below the diagonal) and late sown condition (above diagonal) in Chitwan

	DTH	DTM	GFP	PH	TKW	GY
DTH	1	.381*	-.736**	.858**	-0.284	-0.21
DTM	0.302	1	.345*	.538**	-0.131	-.213*
GFP	-.860**	0.227	1	-.477**	0.193	-.057*
PH	-0.284	0.131	.360*	1	-0.216	-0.167
TKW	-.411*	-0.064	.386*	0.203	1	-0.146
GY	-0.114	.042*	.139*	0.282	-0.322	1

Significant traits are denoted by * for p < .05, ** for p < .01, and *** for p < .001. DTH = Days to heading, DTM = Days to maturity, GPF= Grain filling period, PH= Plant height, TKW= Thousand kernel weight, GY= Grain yield

According to the correlation, late maturing genotypes are excellent for heat-friendly situations whereas early maturing genotypes are best for heat-stressed environments. Grain yield was negatively correlated with days to heading (DH) and days to maturity (DM) in the late season, meaning that faster crop maturation reduces exposure to extended heat stress, resulting in higher grain yield (GY). In the normal season, grain yield had a negative correlation with heading days (HD) and a positive correlation with maturity days (MD) and grain filling duration (GFD), indicating that a longer grain filling period leads to a greater increase in grain yield (Upadhyay, 2020). Plant height also has negative correlation with grain yield in late season that shows due to heat stress plant gain their growing degree days earlier which results lowering height of the plant (Tiwari et al., 2017). Thousand kernel weight has negative correlation in both late and normal season indicating increase in weight of grain lowers number of grain lowering the yield of the crop (Nukasani et al., 2013). Grain filling period has significantly negative correlated with heading days and positively correlated with maturity days in both the seasons. It also has significantly positively correlated with grain yield in both seasons, which indicates crop yield significantly increases with increase in grain filling period of wheat (Okechukwu et al., 2016; Brdar et al., 2008). The correlation suggests that early-maturing genotypes are better suited for heat-stressed environments, while late-maturing genotypes are more appropriate for heat-favorable conditions. Grain yield was negatively correlated with days to heading (DH), days to maturity (DM), and grain filling duration (GFD) in the late season, indicating that faster crop maturation reduces exposure to extended heat stress, resulting in higher grain yield (GY). In contrast, DH, DM, and GFD were positively correlated with GY in normal seasons, implying that a longer crop maturity period, particularly with an extended grain filling period, significantly contributes to increased grain yield. This indicates that late-maturing genotypes adapt well to favorable temperature conditions, and selecting for longer maturity periods may be beneficial for higher grain yield, except under intense and prolonged heat stress, particularly late in the growing season.

Broad sense heritability and genetic advance estimates of the studied traits

Heritability was found to be higher in normal sowing condition than late sown condition and ranged from 94% to 46% (Table 4). The highest mean broad sense heritability was found to be 91% of the trait plant height whereas lowest broad sense heritability was found to be 68% of the trait maturity days. Genetic advance as percentage of mean was found to be higher in normal season for all studied traits except for grain yield. Genetic advance as percentage of mean was categorized as low (0-10 %), moderate (10-20 %) and high (≥20%). The highest mean genetic advance as percentage of mean was found to be 36 for the trait grain yield and lowest mean GAM was found for the trait maturity days which has value of 1.95. High mean genetic advance as percentage of mean was found for the traits thousand kernel weight (31.36) and grain yield (36) whereas moderate genetic advance as percentage of mean was found for the traits grain filling period (11.07) and plant height (10.47). Low genetic advance as percentage of mean was found for the traits heading days (7.39) and maturity days (1.95).

Table 4. Heritability and Genetic advance of twelve wheat genotypes in normal and late sown condition in Chitwan

Traits	Heritability			Genetic advance as % of mean		
	Normal	Late	Mean	Normal	Late	Mean
DTH	0.87	0.88	0.87	7.62	7.16	7.39
DTM	0.9	0.46	0.68	2.6	1.3	1.95
GFP	0.8	0.75	0.77	11.44	10.7	11.07
PH	0.94	0.89	0.91	16.54	4.4	10.47
TKW	0.85	0.74	0.79	38.06	25.07	31.56
GY	0.76	0.62	0.69	27.68	44.32	36

DTH = Days to heading, DTM = Days to maturity, GPF= Grain filling period, PH= Plant height, TKW= Thousand kernel weight, GY= Grain yield

Upadhyay et al., (2019) earlier reported high heritability estimates for DH, DM, GFP, PH, TKW and GY which are close to results of the present study. Maturity days have lower heritability in late season due to highly influenced by heat stress condition whereas in normal condition it has less influenced by environmental factors. Heritability estimates for various traits depend on the genetic makeup of the breeding materials being studied. Therefore, understanding these values in the materials of interest is crucial for breeders (Herbert et al., 1955). Higher heritability estimates typically imply simpler selection procedures (Mazurkievicz et al., 2019). Generally, if a trait is influenced by non-additive gene action, it may exhibit high heritability but low genetic advance, whereas a trait governed by additive gene action would show high values for both heritability and genetic advance (Okechukwu et al., 2016). However, heritability values alone do not indicate the genetic progress achievable by selecting the best individual; instead, considering heritability estimates alongside genetic advance is considered more informative (Shenoda et al., 2021). Genetic advance in percentage of mean gives more precise result in comparison to only genetic advance. Genetic advance as percent mean was categorized as low (0-10%), moderate (10-20% and high (≥20%) (Herbert et al., 1955). In the present study moderate genetic advance as percent of mean was estimated for grain yield kg ha-1 (11.98%) and other traits showed low genetic advances (<10%). This indicates observed characters among tested genotypes governed by non-additive gene action and thus heterosis breeding, family selection and progeny testing methods are used for improvement on such traits. High broad heritability and low genetic advance estimates observed in DH, DM indicate that Observed characters among tested genotypes governed by non-additive gene action and thus heterosis breeding, family selection and progeny testing methods is used for improvement on such traits. The high values of genetic advance and heritability for the trait TKW and GY indicates that the trait is under additive gene effects, and therefore selection for low kernel weight and higher grain yield will be effective (Upadhyay et al., 2019). Plant height, which showed the highest genetic advance and high to moderate heritability estimates, will be crucial for a heat tolerance breeding program. The traits having high values of heritability coupled with moderate genetic advance as percent of the mean namely, plant height and grain filling period suggest that selection for improvement of these characters may be satisfying. However, high heritability with high GAM as reported in GY suggest additive gene effects, thus the selection will be rewarding. Direct selection of grain yield can be done to improve heat tolerance in breeding program.

Conclusion

Heat tolerance is a quantitative trait that is promoted by several components. The significant impact of heat stress on wheat performance, particularly on grain yield, highlights the urgent need for breeding programs focused on heat tolerance. However, the notable genotypic effects observed indicate that there is considerable genetic variability within the wheat germplasm, which can be utilized in developing heat-tolerant varieties. Based on the study, genotypes MYT1718-24, MYT1718-06, MYT1819-22 had high yield potential under both conditions. Thus, these genotypes can be used in breeding programs for developing heat tolerance wheat varieties.

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Author's declaration and contribution
The authors have no conflict of interest to disclose. Conceptual framework, data collection and analysis were performed by Koshraj Upadhyay. Shambhu Katel commented on previous versions of the manuscript. Similarly, the final version of the manuscript was approved by all.

Data Availability Statement
Data are available upon request.

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