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GENETIC VARIABILITY PATTERNS FOR NORMALIZED DIFFERENCE VEGETATION INDEX UNDER TERMINAL HEAT STRESS IN BREAD WHEAT (*TRITICUM AESTIVUM* L.)

Shivani Upadhyay[1], Sushma Tiwari[2]*, Pardeep Beniwal[1], Ayushi Soni[1], Niyati Jain[1]

[1]Department of Genetics and Plant Breeding, College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh, India-474002

[2]Department of Plant Molecular Biology and Biotechnology, College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh, India-474002

*Corresponding author E-mail: sushma2540@gmail.com

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ABSTRACT

One of the major constraints in wheat production is to sustain the potential yield even under high temperatures. Breeding for abiotic stress reflects the insight of the plant breeder to utilize the existing genetic variation to the utmost level to improve stress tolerance. Normalized Difference Vegetation Index (NDVI) is a robust metric to determine vigour of vegetation and vegetative stress and is widely used to elucidate wheat productivity under heat stress. The present study evaluated genetic variation for NDVI at different growth stages in forty-two advanced breeding lines of wheat during the rabi season (2021-22). The experiment was carried out using randomized block design in two replications. NDVI was determined for all the growth stages and genotypes differed significantly at each stage and a decline of NDVI from booting to maturity was observed ranging from 5.17% in Accession no. 26 to 16.42% in Accession no. 24. Late sowing markedly reduced grain yield by 36.19% compared with timely sown conditions. NDVI recorded at the milking stage showed the strongest association with grain yield ($R^2 = 0.58$), indicating its reliability as a indirect measure of selection for identifying promising wheat lines which sustains high yield under stressed conditions. a selection criterion under stress environments. The findings suggest that despite stress conditions, high-yielding accession nos. 4, 9, 18, 37, and 39 sustained appreciable NDVI, indicating better canopy persistence.

***Key words*:** Bread wheat, NDVI, Heat stress, Growth stage, Genetic variability

Introduction

Bread wheat (*Triticum aestivum* L.) is manifested as the predominant cereal crop grown worldwide and consumed as a staple food grain by almost 2.5 billion of the world's population (Shewry 2009; Ramadas *et al.*, 2019). It is known to be cultivated in various climatic conditions owing to its broad adaptability. Wheat yield is increasing by 0.9% per year which is significantly lower than the required rate of ~2.4% per year by 2050 (Ray *et al.*, 2013). At these rates, it is somewhat conclusive that the global production is far below than what is required in keeping with the large expected demands of the future (Joshi *et al.*, 2007). The crop has been recognised as the largest contributor with respect to world grain production (approximately 30%) and world grain trade (nearly 50%) (Akter and Islam 2017; Curtis & Halford, 2014). In developing countries like India, the increasing demand for staples due to population growth was able to keep pace with the food production by virtue of the green revolution (Pingali 2012). Wheat production has touched a milestone output of 107.59 million tons covering an area of approximately 31.45 million hectares with a record nationwide average yield of 3.42 tons per hectare during the year 2019-20 at the national level (DAC & FW 2021). Major boost in ambient temperature led to severe circumstances during grain development and physiological traits, simultaneously (Tyagi and Pandey 2022). To gain sustained homeostasis and survival of growing plants exposed to higher temperatures, it is extremely important to endorse such wheat cultivars which give higher yields even when exposed to higher temperatures (Mishkind *et al.*, 2009; Farhad *et al.*, 2023). Heat stress can significantly decrease both the number of grains per spike and the individual grain weight, depending on the timing and severity (Asseng *et al.*, 2013). Exploring possible ways to break the plateau of shrinking yields, especially in stress-prone environments around the world, is crucial.

Normalized Difference Vegetation Index (NDVI) is a promising criterion of non-destructive estimation of plant biomass and proximal canopy sensing for easy, time saving and high accuracy measurements as destructive sampling is hectic, expensive and time consuming (Hassan *et al.*, 2019; Babar *et al.*, 2006). It is derived by subtracting the near-infrared (NIR) to the red (RED) reflectance and dividing it to their sum (Weier and Herring 2000). The ratio has been monitored throughout different growth phases in previous investigations for wheat crop to determine its association with grain yield. Although such studies have assessed crop vigour and stress response under uniform sowing conditions. There is limited information regarding stage-wise NDVI profiling under contrasting sowing regimes used to impose terminal heat stress. As abiotic stresses affect wheat during different phenological stages, it is now considered that vegetative indices also differ significantly under normal (meteorological) and stress conditions (such as high temperature, drought, and disease) (Ryu *et al.*, 2019). Therefore, the difference undergone with respect to time is required to be investigated. Different researchers deployed NDVI as a metric trait to indirectly select for desirable types in breeding programmes which ultimately served as an efficient tool for bulk germplasm screening under heat stress (Lopes and Reynolds 2012; Sultana *et al.*, 2014). Therefore, the present study aimed to thoroughly examine the germplasm for the genetic variability in NDVI, to characterize multi-stage NDVI dynamics under timely and late sowing conditions, quantify stage-specific associations between NDVI and grain yield and identify genotypes exhibiting stable canopy performance under heat stress.

Materials and Methods

Plant Material

The current study comprises of forty-two advanced breeding lines of wheat with different genetic background along with a national check (Table 1) which represent South Asian Bread Wheat Genomic Yield Trials (SABWGPYT) panel developed and evaluated within coordinated multi-environment testing targeting terminal heat prone agro-ecologies of South Asia. These lines had been pre-selected for their improved adaptation to terminal heat stress and yield stability across contrasting

Table 1: Recorded mean grain yield under normal and late sown conditions and decrease in NDVI (in per cent) for 42 wheat genotypes.

Accession No.	GID	NDVI Red (%)[1]	Grain Yield	
			NS	LS
1	8237097	7.42	6.05	3.80
2[2]	304660	13.33	7.35	5.91
3	8237288	5.58	7.31	4.08
4	8235620	6.75	5.96	5.72
5	8235735	7.58	7.37	3.63
6	8236241	6.08	7.52	3.50
7	8236771	7.25	7.96	4.58
8	8243369	8.33	8.25	4.48
9	8243467	12.75	4.77	5.83
10	8243555	13.92	7.90	3.99
11	8243589	8.67	5.49	4.56
12	3872194	7.58	6.64	2.90
13	8243716	11.83	7.70	4.75
14	8244046	7.17	6.33	4.46
15	8244112	8.25	6.26	4.19
16	8244469	6.33	6.46	3.19
17	8245477	7.67	8.09	4.92
18	8246228	10.83	6.26	6.06
19	8246826	9.58	8.20	5.35
20	6175067	12.75	8.13	4.15
21	8247025	5.83	5.74	3.55
22	8247079	13.42	7.64	3.83
23	8247285	9.58	6.87	5.31
24	8239246	16.42	8.45	4.66
25	6341870	13.00	7.94	5.34
26	8240049	5.17	7.42	4.23
27	8240287	10.75	7.50	5.23
28	7400769	5.25	6.62	4.53
29	8240469	11.92	8.19	4.50
30	8240480	5.50	6.32	4.40
31	8241137	14.33	7.59	4.68
32	8241199	15.17	7.43	5.17
33	8241228	10.83	4.88	4.32
34	8241261	8.42	8.03	5.16
35	8241308	8.92	7.25	4.06
36	8242391	10.50	7.06	4.23
37	7398245	5.92	8.27	5.74
38	8242394	12.17	8.08	3.98
39	8242418	11.83	6.77	6.15
40	8242649	7.75	7.12	4.76
41	8243030	10.33	5.72	3.40
42	8243218	14.58	7.13	3.02

Table 2: The pooled analysis of variance across two environments for all morphological traits.

Source of variation	df	Mean sum of squares							
		DTH	DTA	DTM	SL	PH	FLA	TGW	GY
Environment (E)	1	521.5**	1136.7**	7150***	4.534	8566**	1098.7*	4539**	1140.3**
Genotypes (G)	41	51.09***	43.87***	38.24***	2.971***	64.61***	35.61***	54.73***	6.432***
G*E	41	7.98***	6.67***	5.28***	0.661	13.74***	15.57	8.58	6.500***
Error	82	2.30	2.25	1.77	0.485	5.88	10.34	6.14	1.267

*** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; DTH, days to heading; DTA, days to anthesis; DTM, days to maturity; SL, spike length; PH, plant height; FLA, flag leaf area; TGW, thousand grain weight; GY, Grain yield

sowing environments in yield trials conducted at research stations of BISA, Jabalpur.

Field experiment

The on-farm experiment took place at the Borlaug Institute for South Asia (BISA) research station in Jabalpur, Madhya Pradesh (23°10'7.6"N; 79°55'55") at an elevation of about 407 meters above sea level representing the Central Zone during two planting times in 2021-22 crop season. The study was carried out in coordination with the Department of Plant Molecular Biology & Biotechnology, College of Agriculture R.V.S.K.V.V., Gwalior. Standard month-wise meteorological data was fetched from the agrometeorological observatory of BISA, Jabalpur Madhya Pradesh for the growing season (Fig. 1). The trials were conducted in randomized block design with two replications. In each replication, the plot size was 5 square metre (approximately) and the lines were sown in six rows that were 22 cm apart and 3.8 m in length. Standard and recommended package of practices for the wheat crop was stringently followed. The fields were sown under timely (between 15 to 21 November) and late conditions (between 18 to 25 December) to coincide grain filling phase with consequent rising temperatures. With a progressive increase in maximum temperatures in the months of March (36.65°C) and April (41.33°C); reproductive phase of the late sown crop coincided with this period of elevated thermal exposure (>35°C), whereas the timely sown crop experienced comparatively moderate temperatures below 30°C during grain filling. Concurrently, minimum temperature increased by over 11°C from February (4.88°C) to April (16.28°C). Thus, different sowing dates gave assurance of temperature differences during later stages of growth. It was wholly ensured that none of the plots suffered drought conditions to prevent any potential confounding effects with stress caused by heat.

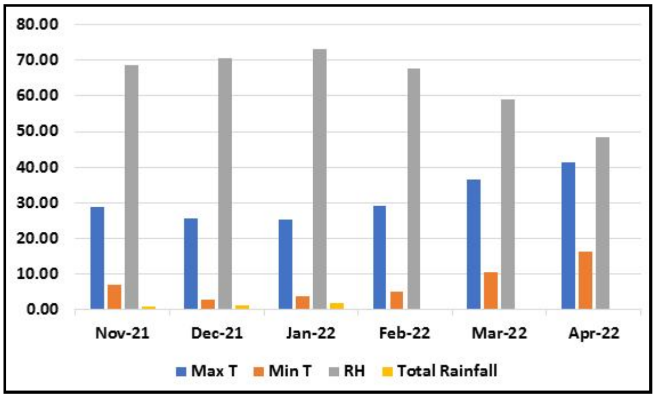

Fig. 1: Month-wise meteorological data for the Rabi season of 2021-22, recorded at agrometeorological observatory of BISA, Jabalpur Madhya Pradesh.

Phenological study and trait analysis

Agronomic practices were uniformly applied to all the genotypes throughout the growing period. Phenological stages, such as booting (Z45), heading (Z59), anthesis (Z69), milking (Z75), dough (Z85) and maturity (Z90), were recorded for each genotypes according to Zadoks et al. (1974). Morphological traits, including days to heading (DTH), days to anthesis (DTA). days to maturity (DTM), plant height (PH), spike length (SL) and thousand grain weight (TGW) were recorded for five plants per replication for each genotype. Flag leaf area (FLA) was estimated as FLA (cm^2) = Flag leaf length × Flag leaf width × 0.83 (Xue *et al.*, 2013). Normalized Difference Vegetation Index [NDVI = (NIR-R)/(NIR+R)], where NIR is near-infrared and R is red) (Tucker 1979) measurements were recorded at or near Zadoks growth scale as described by Zadoks *et al.*, 1974 namely, Z45 (booting), Z59 (heading), Z69 (anthesis), Z75 (milking), Z85 (dough) and Z90 (maturity) using a Handheld GreenSeeker. Similarly, Canopy Temperature (CT) was recorded using handheld infrared Thermometer (LT300) during all the six growth stages. Canopy Temperature Depression (CTD) was calculated (Jackson *et al.*, 1981, Thapa *et al.*, 2018) as the deviation of temperature of crop canopy from the ambient temperature, also known as canopy temperature depression = air temperature (Ta) - canopy temperature (Tc). Both NDVI and CT measurements were recorded during mid-day (11:00 to 13:00) under clear and cloud-free sky, when solar radiation was stable and near peak intensity. Measurements were avoided during windy days to reduce environmental

Table 3: The analysis of variance for NDVI recorded at six growth stages under two sowing conditions.

Source of variation	Df	Mean sum of squares	
		Timely Sown	Late Sown
Genotypes	41	0.0124**	0.009**
Growth stage	5	2.2836**	4.092**
Genotypes * Growth stage	205	0.0058**	1.533**
Replication	1	0.0022	0.0038
Error	251	0.0017	0.002

** Significant at (p< 0.01) per cent LSD

variability and ensure reproducibility of readings. At the end of each cropping season, harvesting was carried out using a small plot combine harvester (Wintersteiger, Austria), and grain yield per plot was measured using a digital scale.

Statistical Analysis

Analysis of variance (ANOVA) and mean comparisons were conducted using SAS 9.4 software. The ANOVA analysis was done for all the growing stages and the interaction effect with genotypes was observed. Reductions in NDVI from booting to maturity stage were calculated. Box plot graphs were generated through R package. Correlation coefficients between NDVI among all stages with reference to grain yield and simple linear regression analysis were performed using R software version 4.5.2 (R Core Team 2025) and MS Excel software, respectively.

Results and Discussion

The pooled ANOVA revealed highly significant differences across all assessed morphological traits under contrasting temperature regimes, indicating substantial genetic variability among the wheat genotypes (Table 2).

Associations between traits under normal and stress environments

The correlation analysis of both environments elaborated the relationship and influence of temperature on grain yield by different morphological and physiological traits (Fig. 2). Grain yield under timely sown conditions showed significantly positive correlations with plant height (0.43), thousand grain weight (0.32) and NDVI (0.42), respectively. Traits like DTH (0.06), DTA (0.18), DTM (0.28) and CTD (0.13) showed positive correlation with grain yield (timely sown). The positive association between CTD and grain yield pertains to genotypes capable of higher canopy cooling ability were able to maintain better stomatal conductance and water uptake, thereby enhancing assimilation and grain filling. Nevertheless, in this study CTD served as a complementary trait with a modest contribution to grain yield for identifying superior genotypes. Furthermore, grain yield under timely sown conditions showed significant negative correlation with FLA (0.35) which suggests that higher leaf area may increase transpiration demand and accelerate senescence leading to reduced grain filling duration. The pattern of influence shifted remarkably for all the traits under late sown heat-stress conditions, where all the traits showed positive correlation with grain yield per plot, except FLA (0.15). Under high temperature conditions, grain yield is associated with canopy cooling and tend to assimilate more with increased remobilization efficiency. A notable shift occurred in the

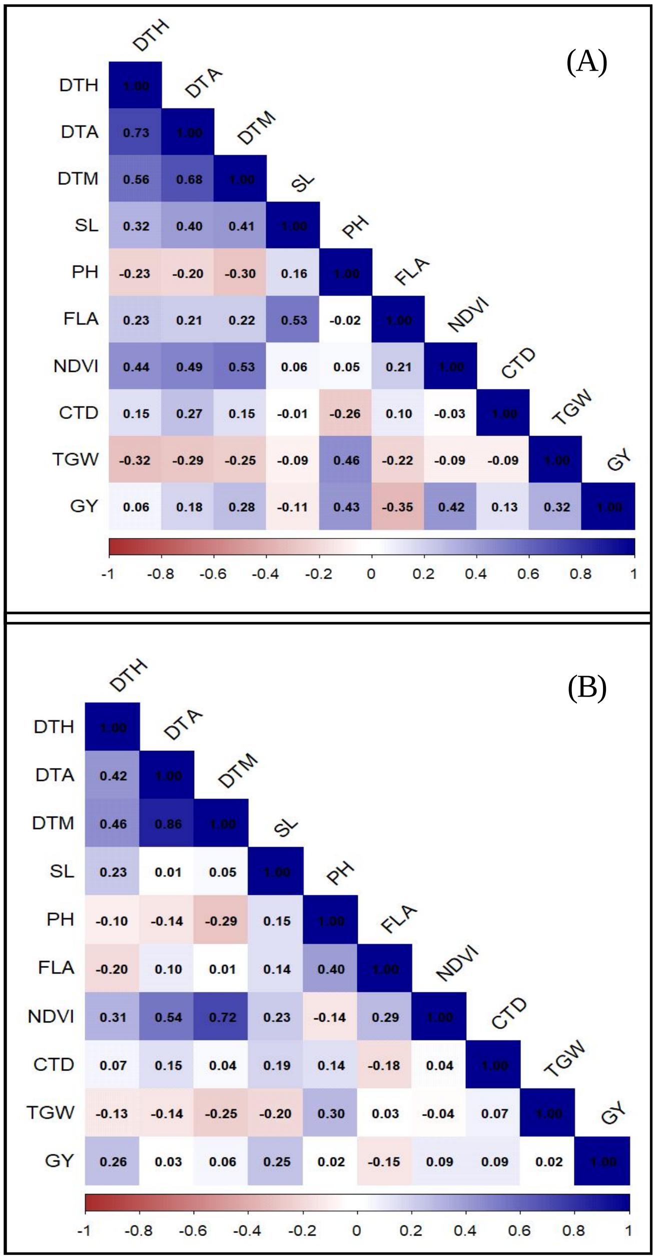

Fig. 2: A Pearson's correlation matrix showing association of morpho-physiological traits for 42 wheat genotypes under (A) timely and (B) late sown conditions.

Table 4: The pooled analysis of variance for grain yield and normalized difference recorded at six growth stages and correlation values with grain yield under normal and late sown conditions.

Source of variation		df	Mean sum of squares						
			B	H	A	M	D	MT	GY
Normal sown	Replication	1	0.000	0.000	0.010	0.001	0.000	0.001	1.468
	Genotypes	41	0.003**	0.001**	0.001**	0.002**	0.012**	0.022**	1.816**
	Error	41	0.001	0.001	0.001	0.001	0.003	0.003	0.475
Late sown	Replication	1	0.011	0.007	0.000	0.070	0.001	0.001	1.575
	Genotypes	41	0.002	0.002**	0.002**	0.006**	0.011**	0.004**	1.381**
	Error	41	0.003	0.001	0.001	0.002	0.004	0.002	0.326

** Significant (p< 0.01); B, booting stage; H, heading stage; A, anthesis stage; M, milking stage; D, dough stage; Mt, maturity; GY, grain yield

behaviour of NDVI, across different temperature regimes. NDVI showed significant and positive correlation under timely sown conditions with DTH (0.44), DTA (0.49) and DTM (0.53), suggesting that late genotypes maintained green canopy at critical growth stages. Also, under late sown conditions, the effect was more pronounced that revealed significant and positive correlation of grain yield with DTH (0.26), DTA (0.03) and DTM (0.06), respectively.

Comparing NDVI across Crop Growth Stages

The analysis of variance for NDVI stated that genotypes differed significantly (p< 0.001) at the six growth stages under both the sowing conditions. Significant genotype (G) and growth stage (GS) interaction was observed under normal and late sown conditions which implies existence of variations in NDVI among the genotypes that differed over various growth stages (Table 3). Similarly, variation for NDVI was seen to be highly significant (p< 0.01) concerning all the growth stages in addition to grain yield suggesting presence of huge amount of variation among the genotypes and sufficient scope for further improvement (Table 4). Significant stage-wise variation was observed based on critical difference (CD) at 5% level for both timely and late sown environments. Differences exceeding the CD value (5%) were considered statistically significant.

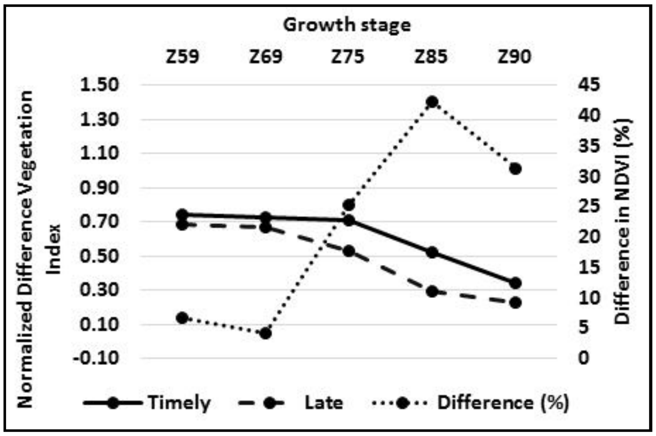

Fig. 3: Pooled NDVI values at different growth stages of 42 wheat genotypes. Reductions in NDVI value at five growth stages represented as difference in NDVI (in per centage). Z59, Ear emergence complete; Z69, Complete anthesis; Z75, Medium milk; Z85, Dough; Z90, Ripening.

The temporal progression of NDVI showed a consistent decline from booting towards maturity, which depicts how the optimal sowing time clusters the genotypes near the upper NDVI range during the early reproductive phases, with values stabilizing between heading to milking followed by sharp decline after milking stage similar to the results of Ramya *et al.*, (2015). This sequential dip in the NDVI values from booting to maturity helped in identifying desirable genotypes that show relatively less reduction and indeed retain high values of chlorophyll even during times of stress. Under stress, the NDVI trajectories show consistently lower values than those observed under optimal conditions. The gap widens particularly from anthesis onwards. Instead of a plateau, stressed plants show a noticeable decline or subdued rise during grain-filling stages (milking to maturity). As expected, towards the end of the crop season (terminal heat stress, anthesis to mid-grain filling stages), the NDVI values decreased sharply as the crop approached maturity. General mean, range and coefficient

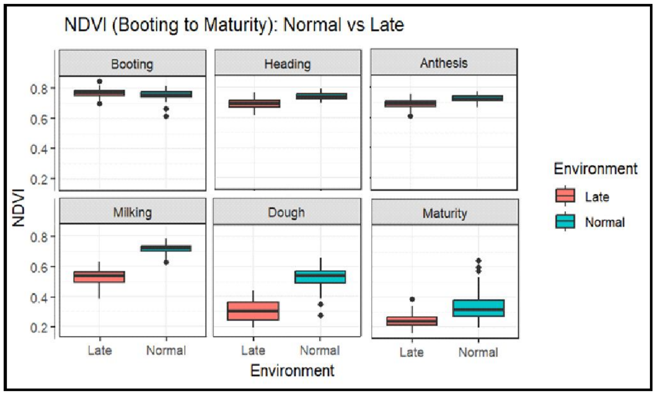

Fig. 4: Box-plots showing NDVI distribution for six growth stages (booting to maturity) under normal and late sown conditions.

Table 5: Mean, range and coefficient of variation for NDVI and Grain Yield under normal and late sown conditions for 42 genotypes.

Traits	Zadoks growth scale	Normal Sown (Timely)				Late Sown (Stress)			
		Mean	Range		CV	Mean	Range		CV
			Min	Max			Min	Max	
Booting	Z45	0.76	0.62	0.82	4.25	0.77	0.70	0.85	6.52
Heading	Z59	0.74	0.70	0.79	4.35	0.69	0.62	0.77	4.00
Anthesis	Z69	0.72	0.67	0.77	3.96	0.65	0.61	0.76	4.61
Milking	Z75	0.71	0.63	0.78	4.98	0.53	0.39	0.63	9.27
Dough	Z85	0.52	0.28	0.66	10.99	0.30	0.20	0.44	19.53
Maturity	Z90	0.35	0.20	0.64	14.71	0.24	0.16	0.39	19.29
GY	-	7.10	4.77	8.45	9.71	4.53	2.90	6.15	12.58

Min, minimum value; Max, maximum value; CV, Coefficient of variation; GY, Grain Yield

of variation as illustrated in the Table 5 was subjected to computation for different growth stages coming under the criterion of Zadoks growth scale. The recorded coefficient of variation for NDVI was comparable for normal and stressed environments ranging from 3.96% to 19.53% as compared to grain yield with 9.71% and 12.58% for timely and late sown conditions, respectively. Maximum CV was noted for Dough and Maturity stages for both conditions. A comparative analysis between timely and late sown conditions revealed mean NDVI values showing a consistent advantage for timely sowing across all phenological stages (Fig. 3). At Z59 (ear emergence), NDVI ranged from 0.70–0.79 under timely sowing compared with 0.62–0.77 under late sowing, corresponding to a 7% reduction. The gap widened at Z75 (milk stage), where minimum NDVI declined to 0.63 in timely sown and 0.39 in late sowing period (25% reduction). The maximum difference occurred at later stages including Z85 (dough stage), resulting in maximum reduction, followed by Z90 (ripening) where NDVI declined under both conditions due to senescence. Also, this trend is represented by the box plots (Fig. 4) which show a clear and consistent variation in NDVI values, with the magnitude of decline varying by growth stages with most pronounced differences during the reproductive and grain-filling stages (Panek *et al.*, 2020; Magney *et al.*, 2016).

Significance of NDVI in yield prediction

Yield losses associated with delayed sowing have been consistently attributed to shortened grain-filling duration and accelerated senescence caused by exposure to elevated temperatures during reproductive development (Sharma 1992; Ortiz et al 2008; Asseng *et al.*, 2015). Under normal sown conditions, mean grain yield of the 42 wheat genotypes varied from 4.77 to 8.45 t/ha whereas it was markedly reduced, ranging from 2.90 to 6.15 t/ha for late sown conditions. Such reduction in yield under terminal heat stress was accompanied by corresponding changes in the canopy greenness as recorded by the NDVI in six growth stages. The extent of NDVI reduction from the booting to the dough stage varied among genotypes, ranging from 5.17% in Accession no. 26 to 16.42% in Accession no. 24. The range between the maximum and minimum NDVI values widened progressively from the booting to the maturity stage under both the conditions. A similar trend was observed between the milk and dough stages, where the

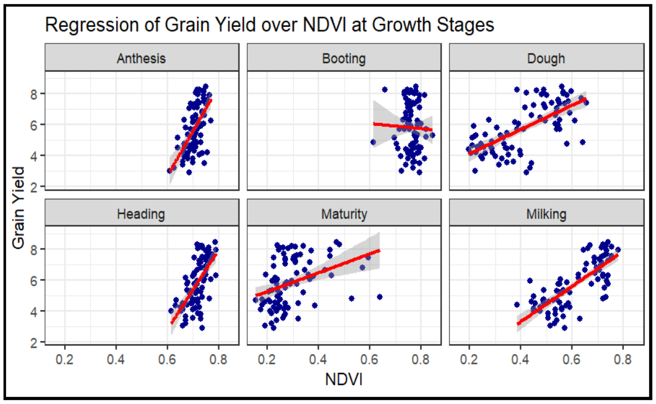

Fig. 5: Regression of grain yield over normalized difference vegetation index (NDVI) from booting to maturity stage in 42 wheat genotypes.

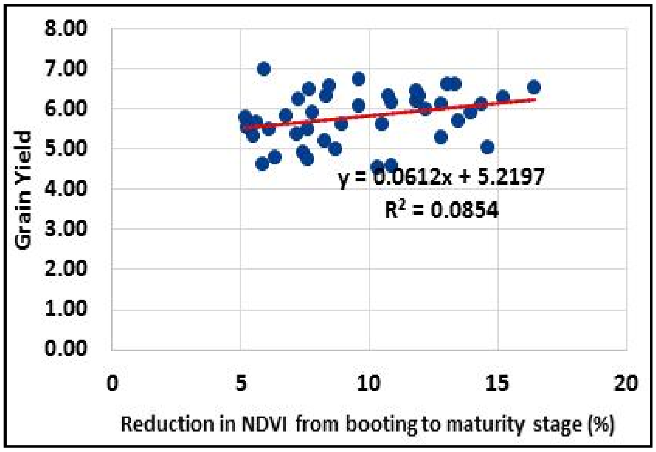

Fig. 6: Regression of grain yield over reduction in NDVI from booting to maturity stage in 42 wheat genotypes.

difference between both the conditions expanded sharply from 4% to 42%. Although the differences in NDVI among genotypes were statistically significant at all growth stages, the magnitude of variation was markedly greater at the dough stage compared with earlier stages. Furthermore, the most pronounced decline in NDVI between successive growth stages occurred during the transition from milk to dough. Stage-wise regression analysis between grain yield and NDVI revealed varying degrees of association at each stage (Fig. 5). NDVI at booting stage showed a very weak and non-significant relationship with GY (R^2=0.001). At the heading and anthesis stages, there were significant correlations with yield but the association was limited at these reproductive stages, hence the predictive strength of NDVI remained low. A strong positive association was estimated between GY and NDVI at later growth stages such as milking and dough stage. Hence, the regression model revealed that NDVI at later growth stages explained a substantial proportion of variability in GY. NDVI at the milking stage accounted for the highest variability (R^2=0.584), followed by dough (R^2=0.435) and heading (R^2=0.390) stages. Therefore, NDVI measurement at the milking stage is the most reliable and practical stage for breeder-oriented selection under late sown (heat stress) environments. Linear regression studies in previous reports of Hazratkulova *et al.*, 2012 have similarly concluded that late-season NDVI and canopy vigour are reliable indicators of yield potential.

NDVI showed significant positive associations with grain yield predominantly at later reproductive stages, which suggests that the maintenance of green canopy and sustained photosynthetic activity during grain filling plays a decisive role in determining grain yield. The observations aligned with the work of Sharma *et al.*, (2011), Marti *et al.*, (2007) and Ramya *et al.*, (2015). Importantly, Freeman *et al.*, 2003 demonstrated that NDVI recorded at vegetative to early reproductive stages (equivalent to Zadoks Z45–Z69) retained meaningful correlations with final grain yield, whereas measurements taken closer to maturity failed to capture yield variability due to saturation effects and senescence-driven spectral noise. This observation directly supports the current findings under late-sown (heat-stressed) conditions, where accelerated phenological development shortened the effective window during which NDVI could discriminate genotypic differences.

Under stressed condition, several high yielding genotypes (Accession no. 4, 9, 18, 37, 39) maintained appreciable mean NDVI values. Also, some genotypes such as Accession no. 6, 9, 14, 15, 32, 33 and 37 showed consistently higher NDVI across all growth stages despite of heat stress. In contrast, some low yielding genotypes (Accession no. 7, 22, 26) exhibited NDVI values comparable to those of the highest-yielding genotypes from the booting to milking stages, but showed a pronounced decline during the dough and maturity stages. Regression analysis between grain yield and reduction in the NDVI from booting to maturity revealed a weak negative relationship (r= 0.085), explaining only 8.5% of the variation in grain yield (Fig. 6). Hence, higher NDVI values do not always translate to higher yield under heat stress, so the association between the recorded NDVI values at different growth stages and grain yield is way more meaningful at later reproductive stages than early growth stages. The high-yielding genotypes (Accession no. 4, 9, 18, 37, 39) exhibited decline in the NDVI values from flowering to the dough stage, ranging from 23% to 53%. In contrast, the low-yielding genotypes (Accession no. 7, 22, 26) showed substantially greater NDVI reductions over the same period, with 64%, 63% and 62% decline. Overall, the study demonstrates that NDVI is not a static indicator of yield potential but a dynamic measure of canopy functionality whose predictive value varies with growth stage and temperature regimes. For wheat populations, several researchers identified such indices for high-throughput phenotyping in contrast to various physiological indices such as chlorophyll content, photosynthesis and biomass (Kumar *et al.*, 2023; Cabrera-Bosquet *et al.*, 2011; Li *et al.*, 2020).

Conclusion

In this investigation, high temperature stress was successfully employed by staggered sowing in the month of December. The study confirmed substantial genetic variability among wheat genotypes under contrasting temperature regimes. NDVI exhibited stage-specific differences with its relevance becoming more pronounced during the reproductive phase. Stage-wise regression suggests that NDVI measured during reproductive stages explained a greater proportion of yield variability compared to early vegetative stages. Despite heat stress, accession no. 9 and 37 demonstrated relatively stable performance, combining higher grain yield with sustained NDVI across growth stages followed by Accessions 4, 18 and 39 which also exhibited comparatively better yield and moderate NDVI stability. These genotypes may be considered promising candidates for further evaluation under heat stress environments. The findings further highlight the utility of NDVI as a rapid yet non-destructive selection criterion to choose the superior performing genotypes under terminal heat stress. The identified accessions would be of great significance as parents for development of thermotolerant varieties for future abiotic stresses breeding programmes and serve as important germplasms to understand the mechanism related to tolerance to heat in wheat.

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