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# Morpho-physiological variation in advanced lines of wheat under elevated temperature

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## Abstract
Global warming is predicted to increase temperature by $5^0$C by the end of this century. Winter crop to withstand under cooler temperature, it might be changes in cropping system and the global warming demand identification of identification of wheat varieties to high temperature. Wheat is a thermo-sensitive long-day crop requires relatively low temperature for satisfactory growth and high temperature is a major determinant of its growth and productivity. With this objective fourteen wheat genotypes were evaluated for different temperature regimes under controlled condition at Phytotron facility during *Rabi,* 2014-15 in FCRD with two replications. The experiment was conducted in three steps as germination test, seedling growth test and morpho-physiological analysis for growth and yield variations. Various temperature treatment levels had substantial effects on germination and early vegetative growth and morpho-physiological traits. The 15/$15^0$C temperature favours for 100% germination and better germination properties, whereas, 20/$20^0$C and 25/$15^0$C found good for optimum germination and seedling growth characters in wheat. The 25/$20^0$C temperature was found better for earlier crop phenology, better vegetative growth, physiological parameters, biochemical characters and yield and yield contributing characters. The genotypes, LOK-54, LOK-1, DBW-17 and HALNA were superior for maintaining better germination and it's properties, however, NIAW-2874, NIAW-2892, NIAW-2837 and PBW-343 were good for seedling growth. As per the comparison between lower and elevated temperatures, NIAW-2809, NIAW-2874, NIAW-2859 and NIAW-2837 were found superior at elevated temperature for better vegetative growth, physiological parameters, biochemical characters and yield and yield contributing characters. Therefore, these genotypes might be considered for further breeding programme for crop improvement in wheat at elevated temperature regime for respective characters.

**Keywords:** Germination test, Seedling growth test, growth and yield variation, temperature regimes

## Introduction
Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development. Heat stress is a complex function of intensity (temperature in degrees), duration and rate of increase in temperature. The night temperatures are major limiting factors others have argued that day and night temperatures do not affect the plant independently and that the diurnal mean temperature is a better predictor of plant response to high temperature with day temperature having a secondary role (Peet and Willits, 1998) [20]. At very high temperatures, severe cellular injury and even cell death may occur within minutes, which could be attributed to a catastrophic collapse of cellular organization. At moderately high temperatures, injuries or death may occur only after long-term exposure. Direct injuries due to high temperatures include protein denaturation and aggregation, and increased fluidity of membrane lipids. Indirect or slower heat injuries include inactivation of enzymes in chloroplast and mitochondria, inhibition of protein synthesis, protein degradation and loss of membrane integrity (Howarth, 2005) [13]. Elevated temperatures can cause considerable pre- and post-harvest damages, including scorching of leaves and twigs, sunburns on leaves, branches and stems, leaf senescence and abscission, shoot and root growth inhibition, fruit discoloration and damage, and reduced yield. At the whole plant level, there is a general tendency of reduced cell size, closure of stomata and curtailed water loss, increased stomatal and trichomatous densities, and greater xylem vessels of both root and shoot (Anon *et al*., 2004) [4]. Different phenological stages differ in their sensitivity to high temperature; however, this depends on species and genotype as there are great internal intra-specific variations (Howarth, 2005) [13]. In general, plants tend to maintain stable tissue water status regardless of temperature when moisture is ample; however, high temperatures severely impair this tendency when water is limiting. Under stress, different plant species may accumulate a variety of osmolytes. Alterations in various photosynthetic attributes under heat stress are good indicators of thermotolerance of the plant as they show correlations with growth.

Any constraint in photosynthesis can limit plant growth at high temperatures. Photochemical reactions in thylakoid lamellae and carbon metabolism in the stroma of chloroplast have been suggested as the primary sites of injury at high temperatures. Therefore, the present study was planned to study the effect of temperature regimes on germination indices, seedling growth and morpho-physiological analysis for growth and yield variation in wheat.

**Material and methods**

Fourteen wheat genotypes were evaluated for different temperature regimes (15/15 $^0$C, 20/20 $^0$C, 25/15 $^0$C, 25/20 $^0$C and 25/25$^0$C) under controlled condition at Phytotron facility during *Rabi*, 2014-15 in FCRD with two replications. The experiment was conducted in three steps as germination test, seedling growth test and morpho-physiological analysis for growth and yield variations. For germination test, the seed surface sterilized with 10% sodium hypochloride solution for five minutes and wash three times with distilled water. Ten seeds of every genotype sown separately in petri dish covering by Whatman filter paper. The thermo-treatments were given separately in different growth chambers. The 5 ml of Hoagland solution was added in each petri- dish. Number of seeds germinated was counted daily and data was recorded upto 8 days. The root and shoot length and dry matter of seedling were recorded after 8 days. The germination and seedling growth indices under germination test were estimated with the help of following formulae;

| | |
|---|---|
| $\text{Germination percentage (\%)} = \frac{\text{Total number of germinated seeds}}{\text{Total seed sown}} \text{X } 100$ | |
| Promptness index (PI)= nd2 (1.00) + nd4 (0.75) + nd6 (0.50) + nd8 (0.25), where $nd_2$, $nd_4$, $nd_6$ and $nd_8$ = Per cent of seeds observed to germinate after 2, 4, 6 and 8$^{th}$ days after observation | Sammar Raza (2012) [23]. |
| Mean germination time (MGT) = Σ (ni/di)<br>ni: number of germinated seeds and di: day of counting | Ellis and Roberts (1981) [11]. |
| $\text{Coefficient of velocity (CV g)} = \frac{\Sigma N_i}{100} \text{ x } \Sigma (T_i \text{ x } N_i)$ | Kader and Jutzi (2004) [15]. |

For seedling growth test, 5 seeds of genotypes were sown in root trainer block type 150cc 20/25 cell containing mixture of cocopit, bhusa and perlite having zero nutrient value. The 5 ml of Hoagland solution was added in each cavity everyday having good drains. The seedling were harvested at 21 days and observations were recorded on shoot length, root length, seedling length, dry matter of seedlings (dried at 70 $^0$C for 48 hours), fresh weight, turgid weight and dry weight of leaves. The PHSI, RLSI, SLSI and DMSI were calculated as mentioned above. The Relative saturation deficit (RSD) was determined by the formula given by Sammar Raza (2012) [23];

$$\text{PHSI (\%)} = \frac{\text{Plant height of stressed plants}}{\text{Plant height of control plant}} \times 100$$

$$\text{DMSI (\%)} = \frac{\text{Dry matter of stressed plant}}{\text{Dry matter of control plant}} \times 100$$

$$\text{RSD (\%)} = \frac{\text{Fresh weight – dry weight}}{\text{Turgid weight - dry weight}} \times 100$$

The experiment on physiology of growth and yield variation was undertaken in Automated Polyhouses in pot culture at 20/15 and 25/20 $^0$C day and night temperature. Five seedlings were grown in pots having growth media of clay, cocopit and vermiculite and perlite. The observations on crop phenology, morpho-physiological, biochemical and yield contributing characters were recorded.

The observations on net photosynthetic rate, transpiration rate and stomatal conductance were recorded at 50% flowering with the help of portable Infrared Gas Analyzer (IRGA; Model Portable Photosynthesis System LI 6400, LI-COR Inc, Lincon, Nebraska, USA). The observations were made between 11.00 and 13.00 hr on fully expanded young leaves of three randomly selected plants for each genotype at 20/15 and 25/20 $^0$C. Canopy temperature (CT) and CTD (ºC) were recorded at 50% flowering with the help of infra-red thermometer (IRT). SPAD index was estimated nondestructively, using SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, NJ, USA).

Proline content in leaf tissues were determined by using the acid ninhydrin reagent as per the method described by Bates *et al*. (1973) [7]. The level of lipid peroxidation is measured in terms of thiobarbituric acid reactive substance (TBARS) content. The observations were recorded on panicles plant$^{-1}$, grains pnicle$^{-1}$, grain yield plant$^{-1}$ and harvest index (%) for each genotype on five plants were recorded at harvesting under both the temperatures. The data obtained from germination test, seedling test and physiological analysis for growth and yield variation were analysed by using factorial completely randomized design (Panse and Sukhatme 1985) [19].

**Results and Discussion**

**Effect of temperature regimes on seed germination properties**

Germination demarcates the transition from the seed being dependent on food sources from the mother plant to an independent plant capable of taking up nutrients and growing independently. Hence, germination makes up the last link in the chain of seed handling processes. Seeds are relatively resistant to environmental impact, germinating seeds and young seedlings are often very vulnerable. Once germination has commenced, water, temperature and light stress can easily be fatal. Therefore the best possible conditions during germination and establishment period are crucial. Light, temperature and moisture are the three main factors which influence germination. During seedling establishment, conditions and properties of growth medium, e.g. such factors as pH, salinity and drainage become increasingly important.

The germination percentage and promptness index were statistically significant for temperature regimes, however, it was non-significant among genotypes and it's interaction effects. The temperature at 15/15 $^0$C recorded 100% germination in all the genotypes, which was declined by elevated temperatures to the tune of 98.57, 92.50, 87.14 and 78.21% at 20/20 $^0$C, 25/15 $^0$C, 25/20 $^0$C and 25/25 $^0$C, respectively. Similarly, temperature at 15/15 $^0$C (24.51) maintained higher promptness index which was declined by elevated temperatures to the tune of 23.93, 22.30, 20.17 and 18.23 at 20/20 $^0$C, 25/15 $^0$C, 25/20 $^0$C and 25/25 $^0$C, respectively (Table 1). On an average the genotypes, LOK-54 (95.00%), LOK-1 (94.00%), DBW-17 (93.00%) and HALNA (93.00%) recorded higher germination percentage, whereas, DBW-17 (22.55), LOK-54 (22.43) and HALNA (22.40) maintained higher promptness index. It inferred that, the temperature range between 15 and 20$^0$C and genotypes, DBW-17, LOK-54 and HALNA were found suitable for better germination and promptness index.

**Table 1:** Germination and it's properties as influenced by wheat genotypes under various temperature regimes

| Genotype | 15/15$^0$C | 20/20$^0$C | 25/15$^0$C | 25/20$^0$C | 25/25$^0$C | Mean | 15/15$^0$C | 20/20$^0$C | 25/15$^0$C | 25/20$^0$C | 25/25$^0$C | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Germination percentage (%)** | | | | | | **Promptness index (%)** | | | | | |
| NIAW-2792 | 100.0 | 95.0 | 95.0 | 85.0 | 75.0 | 90.0 | 24.50 | 23.63 | 23.25 | 20.25 | 17.75 | 21.88 |
| NIAW-2809 | 100.0 | 100.0 | 90.0 | 85.0 | 75.0 | 90.0 | 23.63 | 23.63 | 21.13 | 20.25 | 17.75 | 21.28 |
| NIAW-2837 | 100.0 | 100.0 | 95.0 | 85.0 | 75.0 | 91.0 | 24.50 | 24.50 | 23.75 | 19.75 | 17.75 | 22.05 |
| NIAW-2874 | 100.0 | 95.0 | 90.0 | 85.0 | 80.0 | 90.0 | 25.00 | 23.25 | 21.50 | 20.25 | 17.63 | 21.53 |
| NIAW-2859 | 100.0 | 100.0 | 95.0 | 90.0 | 70.0 | 91.0 | 24.50 | 24.00 | 23.25 | 21.50 | 17.00 | 22.05 |
| NIAW-2891 | 100.0 | 95.0 | 85.0 | 85.0 | 80.0 | 89.0 | 24.50 | 22.75 | 21.25 | 20.25 | 18.13 | 21.38 |
| NIAW-2892 | 100.0 | 100.0 | 90.0 | 85.0 | 85.0 | 92.0 | 24.00 | 23.50 | 22.00 | 19.88 | 19.88 | 21.85 |
| HD-2932 | 100.0 | 100.0 | 100.0 | 90.0 | 65.0 | 91.0 | 24.50 | 24.50 | 23.13 | 17.88 | 15.25 | 21.05 |
| DBW-17 | 100.0 | 100.0 | 95.0 | 85.0 | 85.0 | 93.0 | 24.50 | 24.50 | 23.25 | 20.25 | 20.25 | 22.55 |
| HALNA | 100.0 | 95.0 | 95.0 | 90.0 | 85.0 | 93.0 | 25.00 | 23.75 | 21.88 | 21.13 | 20.25 | 22.40 |
| PBW-343 | 100.0 | 100.0 | 90.0 | 90.0 | 65.0 | 89.0 | 25.00 | 24.50 | 22.00 | 20.13 | 15.25 | 21.38 |
| LOK-54 | 100.0 | 100.0 | 95.0 | 90.0 | 90.0 | 95.0 | 24.50 | 24.50 | 21.88 | 20.63 | 20.63 | 22.43 |
| LOK-1 | 100.0 | 100.0 | 90.0 | 90.0 | 90.0 | 94.0 | 24.50 | 23.50 | 22.00 | 20.00 | 20.00 | 22.00 |
| HD-2189 | 100.0 | 100.0 | 90.0 | 85.0 | 75.0 | 90.0 | 24.50 | 24.50 | 22.00 | 20.25 | 17.75 | 21.80 |
| Mean | 100.0 | 98.6 | 92.5 | 87.1 | 78.2 | 91.3 | 24.51 | 23.93 | 22.30 | 20.17 | 18.23 | 21.83 |
| | **E** | | **G** | | **G x E** | | **E** | | **G** | | **G x E** | |
| S.Em(±) | 1.20 | | 2.00 | | 4.47 | | 0.29 | | 0.49 | | 1.09 | |
| CD 1% | 4.48 | | NS | | NS | | 1.10 | | NS | | NS | |
| | **Mean germination time (days)** | | | | | | **Coefficient of germination velocity** | | | | | |
| NIAW-2792 | 3.29 | 3.13 | 3.13 | 2.75 | 2.42 | 2.94 | 3.05 | 2.77 | 2.27 | 2.34 | 1.78 | 2.44 |
| NIAW-2809 | 3.22 | 3.22 | 2.89 | 2.75 | 2.42 | 2.90 | 3.15 | 3.15 | 2.16 | 2.27 | 1.77 | 2.50 |
| NIAW-2837 | 3.29 | 3.29 | 3.17 | 2.71 | 2.42 | 2.97 | 3.05 | 3.05 | 2.72 | 2.30 | 1.77 | 2.58 |
| NIAW-2874 | 3.33 | 3.12 | 2.91 | 2.75 | 2.47 | 2.92 | 3.00 | 2.76 | 2.52 | 2.26 | 2.08 | 2.52 |
| NIAW-2859 | 3.29 | 3.25 | 3.13 | 2.92 | 2.29 | 2.97 | 3.05 | 3.10 | 2.77 | 2.52 | 1.51 | 2.59 |
| NIAW-2891 | 3.29 | 3.08 | 2.83 | 2.75 | 2.52 | 2.89 | 3.00 | 2.95 | 2.30 | 2.26 | 2.08 | 2.52 |
| NIAW-2892 | 3.25 | 3.21 | 2.93 | 2.72 | 2.72 | 2.96 | 3.10 | 3.15 | 2.51 | 2.27 | 2.27 | 2.66 |
| HD-2932 | 3.29 | 3.29 | 3.16 | 2.83 | 2.08 | 2.93 | 3.05 | 3.05 | 3.20 | 2.60 | 1.34 | 2.65 |
| DBW-17 | 3.29 | 3.29 | 3.13 | 2.75 | 2.75 | 3.04 | 3.05 | 3.05 | 2.77 | 2.26 | 2.26 | 2.68 |
| HALNA | 3.33 | 3.33 | 3.02 | 2.89 | 2.75 | 3.06 | 3.00 | 2.72 | 2.57 | 2.52 | 2.26 | 2.61 |
| PBW-343 | 3.33 | 3.17 | 2.96 | 2.81 | 2.08 | 2.87 | 3.00 | 3.05 | 2.51 | 2.71 | 1.54 | 2.56 |
| LOK-54 | 3.29 | 3.29 | 3.01 | 2.85 | 2.85 | 3.06 | 3.05 | 3.05 | 2.91 | 2.57 | 2.57 | 2.83 |
| LOK-1 | 3.29 | 3.21 | 2.96 | 2.79 | 2.79 | 3.01 | 3.05 | 3.15 | 2.48 | 2.66 | 2.66 | 2.80 |
| HD-2189 | 3.29 | 3.21 | 2.63 | 2.75 | 2.42 | 2.86 | 3.05 | 3.05 | 2.51 | 2.27 | 2.27 | 2.63 |
| Mean | 3.29 | 3.22 | 2.99 | 2.78 | 2.50 | 2.96 | 3.05 | 3.00 | 2.58 | 2.41 | 2.01 | 2.61 |
| | **E** | | **G** | | **G x E** | | **E** | | **G** | | **G x E** | |
| S.Em(±) | 0.03 | | 0.06 | | 0.14 | | 0.06 | | 0.11 | | 0.24 | |
| CD 1% | 0.14 | | NS | | NS | | 0.24 | | NS | | NS | |

The differences among temperature regimes and genotypes were statistically significant, while it was non-significant among it's interaction effects for mean germination time (MGT) and coefficient of germination velocity (CVg). The temperature range at 15/15$^0$C (3.29 days) had availed maximum MGT which was reduced at 20/20 $^0$C (3.22 days), 25/15 $^0$C (2.99 days), 25/20$^0$C (2.78 days) and 25/25 $^0$C (2.50 days). The genotypes, LOK-54 (3.06 days), HALNA (3.06 days), DBW-17 (3.04 days) and LOK-1 (3.01 days) had maximum MGT (Table 1). The CVg was higher at 15/15 $^0$C (3.05) which was declined with elevated temperatures at 20/20 $^0$C (3.00), 25/15 $^0$C (2.58), 25/20 $^0$C (2.41) and 25/25 $^0$C (2.01). The genotypes, LOK-54 (2.83), LOK-1 (2.80) and DBW-17 (2.68) maintained higher CVg. Bahar *et al*, (2011). reported the optimum mean daily temperature for germination ranges from 20 – 25 $^0$C, while the optimum temperature for good tillering is much lower (16–20 $^0$C) and for proper development of the wheat plant the best temperature range is 18-24 $^0$C.

### Effect of temperature regimes on seedling growth

Plant growth and crop yield depend on temperature and it's extremes. The optimum temperature range for $C_3$ crops is 15-20°C and for $C_4$ crops it is 25-30 °C. The variation in temperature requirements and temperature extremes varies widely for different cultivars of the same species, and among species, it varies widely for most crops (Ruan *et al*. 2012) [22]. In the present investigation, differences among temperature regimes and interaction between temperature and genotypes were statistically significant for seedling length, however, it was significant for stress tolerance index among temperature regimes and genotypes. The temperatures at 20/20 $^0$C (42.64 cm), 25/15 $^0$C (34.35 cm), 25/20 $^0$C (33.95 cm) and 25/25 $^0$C (33.23 cm) recorded the higher seedling length than lower temperature at 15/15$^0$C (30.31 cm). The genotypes, LOK-1 (35.87 cm), HD-2189 (35.59 cm), NIAW-2792 (35.32 cm) and LOK-54 (35.30 cm) recorded the higher seedling length at various temperature regimes. The temperature range at

20/20$^0$C (141.35%) recorded higher stress tolerance index (SLSTI) which was declined toward elevated temperatures at 25/15$^0$C (114.41%), 25/20 $^0$C (112.39%) and 25/25 $^0$C (110.34%). The genotypes, LOK-1 (132.88%), HALNA (126.49%), DBW-17 (125.33%) and NIAW-2859 (123.74%) recorded the higher SLSTI (Table 2). Cohen *et al*., (1968) reported rate of root elongation increased two- to three-fold over the 10–20°C temperature range in wheat and barley and root-elongation was positively correlated to seedling weight.

Relative water content (RWC) is closely related to cell volume therefore it may more closely reflect the balance between water supply to the leaf and transpiration rate. This influences the ability of the wheat plant to recover from stress and consequently affects yield and yield stability (Jatoi *et al.* 2011) [14]. It plays a vital role in metabolic and physiological processes that are occurring in plant tissues was found to be high in high yielding cultivars under early and late growing condition in wheat, maintaining the higher water potential (Saxena *et al.*, 2011) [24].

**Table 2:** Seedling growth, relative saturation deficit and dry matter stress tolerance index as influenced by wheat genotypes under various temperature regimes

| Genotype | 15/15$^0$C | 20/20$^0$C | 25/15$^0$C | 25/20$^0$C | 25/25$^0$C | Mean | 20/20$^0$C | 25/15$^0$C | 25/20$^0$C | 25/25$^0$C | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Seedling length (cm)** | | | | | | **Seedling length stress tolerance index (%)** | | | | |
| NIAW-2792 | 31.35 | 41.60 | 36.95 | 32.45 | 34.25 | 35.32 | 132.96 | 116.62 | 103.50 | 109.26 | 115.59 |
| NIAW-2809 | 29.63 | 44.15 | 32.45 | 32.70 | 35.90 | 34.97 | 149.22 | 112.24 | 110.66 | 121.61 | 123.43 |
| NIAW-2837 | 30.75 | 43.10 | 32.85 | 36.65 | 30.45 | 34.76 | 140.30 | 104.85 | 119.47 | 99.30 | 115.98 |
| NIAW-2874 | 28.33 | 42.20 | 32.25 | 32.00 | 31.15 | 33.19 | 150.96 | 121.36 | 114.75 | 111.22 | 124.57 |
| NIAW-2859 | 29.93 | 42.23 | 33.95 | 34.15 | 35.70 | 35.19 | 141.86 | 118.14 | 114.54 | 120.41 | 123.74 |
| NIAW-2891 | 33.13 | 41.40 | 34.80 | 33.90 | 32.15 | 35.08 | 125.12 | 103.67 | 102.33 | 97.08 | 107.05 |
| NIAW-2892 | 30.75 | 40.70 | 32.35 | 37.20 | 29.70 | 34.14 | 132.29 | 104.38 | 120.97 | 96.62 | 113.57 |
| HD-2932 | 29.63 | 40.83 | 34.65 | 33.00 | 30.20 | 33.66 | 138.08 | 113.78 | 111.54 | 102.43 | 116.46 |
| DBW-17 | 29.25 | 42.60 | 33.45 | 35.10 | 35.80 | 35.24 | 145.48 | 113.41 | 120.02 | 122.41 | 125.33 |
| HALNA | 29.04 | 40.15 | 36.15 | 32.35 | 37.05 | 34.95 | 138.55 | 127.46 | 111.96 | 127.98 | 126.49 |
| PBW-343 | 29.79 | 41.90 | 37.15 | 34.30 | 33.25 | 35.28 | 140.92 | 123.56 | 115.20 | 111.78 | 122.86 |
| LOK-54 | 33.79 | 42.48 | 33.70 | 35.95 | 30.60 | 35.30 | 125.41 | 102.03 | 106.48 | 90.77 | 106.17 |
| LOK-1 | 28.50 | 47.70 | 36.10 | 31.95 | 35.10 | 35.87 | 167.67 | 128.55 | 112.16 | 123.14 | 132.88 |
| HD-2189 | 30.55 | 45.85 | 34.15 | 33.55 | 33.85 | 35.59 | 150.08 | 111.69 | 109.81 | 110.81 | 120.60 |
| Mean | 30.31 | 42.64 | 34.35 | 33.95 | 33.23 | 34.89 | 141.35 | 114.41 | 112.39 | 110.34 | 119.62 |
| | **E** | | **G** | | **G x E** | | **E** | **G** | | **G x E** | |
| S.Em(±) | 0.36 | | 0.61 | | 1.37 | | 1.87 | 3.50 | | 7.00 | |
| CD 1% | 1.37 | | NS | | 5.14 | | 7.05 | 13.40 | | NS | |
| | **Relative saturation deficit (%)** | | | | | | **Dry matter stress tolerance index (%)** | | | | |
| NIAW-2792 | 83.21 | 83.80 | 79.31 | 73.55 | 92.06 | 82.39 | 139.98 | 124.64 | 110.56 | 109.17 | 121.09 |
| NIAW-2809 | 85.15 | 85.42 | 81.97 | 79.75 | 92.04 | 84.86 | 91.86 | 104.42 | 92.39 | 91.14 | 94.95 |
| NIAW-2837 | 82.61 | 83.54 | 80.09 | 89.60 | 91.36 | 85.44 | 109.76 | 110.35 | 97.06 | 95.82 | 103.25 |
| NIAW-2874 | 85.87 | 85.18 | 80.87 | 89.40 | 89.51 | 86.17 | 90.26 | 81.98 | 74.28 | 73.24 | 79.94 |
| NIAW-2859 | 87.20 | 87.75 | 73.01 | 72.91 | 85.34 | 81.24 | 122.79 | 123.37 | 107.91 | 106.56 | 115.16 |
| NIAW-2891 | 86.25 | 95.23 | 78.48 | 70.79 | 76.61 | 86.47 | 117.47 | 124.30 | 111.09 | 109.72 | 115.65 |
| NIAW-2892 | 83.57 | 80.52 | 80.45 | 87.08 | 91.91 | 84.71 | 109.94 | 107.96 | 95.39 | 94.05 | 101.84 |
| HD-2932 | 82.16 | 83.29 | 67.46 | 75.87 | 92.28 | 82.41 | 134.87 | 127.09 | 111.62 | 110.34 | 120.98 |
| DBW-17 | 70.29 | 66.26 | 86.31 | 81.57 | 91.81 | 79.25 | 76.22 | 133.54 | 119.51 | 118.29 | 111.89 |
| HALNA | 70.44 | 75.31 | 73.89 | 59.58 | 80.52 | 71.95 | 119.64 | 96.55 | 85.45 | 84.26 | 96.47 |
| PBW-343 | 80.83 | 78.36 | 64.10 | 86.40 | 76.52 | 77.24 | 104.41 | 121.40 | 105.66 | 104.39 | 108.96 |
| LOK-54 | 71.69 | 77.08 | 80.91 | 86.32 | 96.03 | 82.41 | 136.84 | 129.86 | 115.28 | 113.91 | 123.97 |
| LOK-1 | 82.64 | 84.06 | 62.75 | 73.66 | 80.55 | 76.73 | 134.27 | 112.91 | 101.27 | 100.00 | 112.11 |
| HD-2189 | 80.17 | 85.57 | 62.85 | 73.13 | 96.93 | 79.73 | 135.03 | 114.56 | 101.32 | 100.00 | 112.73 |
| Mean | 80.86 | 82.24 | 75.17 | 78.54 | 90.68 | 81.50 | 115.95 | 115.21 | 102.05 | 100.78 | 108.50 |
| | **E** | | **G** | | **G x E** | | **E** | **G** | | **G x E** | |
| S.Em(±) | 1.73 | | 2.90 | | 6.49 | | 1.42 | 2.66 | | 5.33 | |
| CD 1% | 6.50 | | NS | | NS | | 5.37 | 10.21 | | 20.11 | |

The relative saturation deficit (RSD) was statistically significant among temperature regimes, however, differences among temperature regimes, genotypes and it's interaction effects were statistically significant for dry matter stress tolerance index (DMSI). The minimum RSD was recorded at 25/15 $^0$C (75.17%) followed by 25/20 $^0$C (78.54%), 15/15 $^0$C (80.86), 20/20 $^0$C (82.24%) and 25/25 $^0$C (90.68%). The genotypes, HALNA (71.95%), LOK-1 (76.73), PBW-343 (77.24%) and HD-2189 (79.73%) maintained minimum RSD. The temperature at 20/20 $^0$C (115.21%) recorded the higher DMSI which was slightly declined at 25/15 $^0$C and highly at 25/20 $^0$C (102.05%) and 25/25 $^0$C (100.78%). The genotypes, LOK-54 (123.97%), NIAW-2792 (121.09%) and HD-2932 (120.98%) recorded the higher DMSI (Table 2).

**Effect of temperature regimes on crop phenology and morphology:** The vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The root, stem, branches and leaves, all these parts constitute vegetative phase and perform specific functions. In wheat, reproductive stages of crop development are the most vulnerable stage to high temperature and drought stress (Shpiler and Blum 1986). Early vegetative development of crop regulates the reproductive capacity (Awal and Ikeda 2003). The differences among temperature regimes and genotypes were statistically significant for days to initiation of flowering and 50 % flowering, whereas, it was significant for days to physiological maturity among temperature regimes, genotypes and it's interaction (Table 3). The elevated temperature at 25/20 $^0$C (46 & 49 days) had earlier initiation of flowering and 50 % flowering than lower temperature at 20/15 $^0$C (51 & 57 days), respectively. The genotypes, NIAW-2809 (45 & 50 days), NIAW-2874 (46 & 51 days) were found earlier for initiation of flowering and 50 % flowering, respectively. Venkatramanan and Singh (2009) [27] reported that high day and night temperature stress affected the wheat crop phenology by reducing days to flowering as compared to normal ambient temperature condition. The elevated temperature at 25/20 $^0$C (121 days) mature earlier than lower temperature at 20/15 $^0$C (125 days). The genotype, NIAW-2874 (120 days), NIAW-2809, DBW-17 and HALNA (121 days) matures earlier.

The plant height differed significantly among temperatures, genotypes and it's interaction were statistically significant, however, significant differences were observed only among temperatures for number of tillers plant$^{-1}$ (Table 3). The elevated temperatures at 25/20 $^0$C (67.76 cm) maintained arrested growth with the higher number of tillers plant$^{-1}$ (2.75) than lower temperatures at 20/15 $^0$C (70.13 cm & 1.81). Similarly, elevated temperatures at 25/20$^0$C (3.09 dm$^2$) recorded the higher leaf area plant$^{-1}$ than lower temperatures at 20/15 $^0$C (2.91 dm$^2$). The genotypes, LOK-1 (71.89 cm) HD-2189 (71.72 cm), LOK-54 (70.38 cm) and NIAW-2792 (70.17 cm) for plant height; NIAW-2837 (2.75), PBW-343 (2.50), LOK-54 (2.50 and NIAW-2809 (2.38) for number of tillersplant$^{-1}$ and HALNA (3.38 dm$^2$), LOK-54 (3.24 dm$^2$), NIAW-2792 (3.22 dm$^2$) and NIAW-2859 (3.22 dm$^2$) for leaf area plant$^{-1}$ were found promising for respective characters. Cao and Moss (1989) [9] reported that total number of leaves and leaf area were reduced in response to high temperature stress in wheat genotypes.

**Table 3:** Crop phenology and vegetative growth as influenced by wheat genotypes under various temperature regimes

| Genotypes | **Days to initiation of flowering** | | | **Days to 50 % flowering** | | | **Days to physiological maturity** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **20/15$^0$C** | **25/20$^0$C** | **Mean** | **20/15$^0$C** | **25/20$^0$C** | **Mean** | **20/15$^0$C** | **25/20$^0$C** | **Mean** |
| NIAW-2792 | 49.0 | 45.0 | 47.0 | 54.0 | 50.0 | 52.0 | 124.0 | 120.0 | 122.0 |
| NIAW-2809 | 47.0 | 43.0 | 45.0 | 52.0 | 48.0 | 50.0 | 123.0 | 119.0 | 121.0 |
| NIAW-2837 | 49.0 | 46.0 | 47.5 | 55.0 | 51.0 | 53.0 | 125.0 | 121.0 | 123.0 |
| NIAW-2874 | 48.0 | 44.0 | 46.0 | 53.0 | 49.0 | 51.0 | 122.0 | 118.0 | 120.0 |
| NIAW-2859 | 51.0 | 47.0 | 49.0 | 56.0 | 52.0 | 54.0 | 125.0 | 122.0 | 123.5 |
| NIAW-2891 | 53.0 | 48.0 | 50.5 | 57.0 | 53.0 | 55.0 | 127.0 | 123.0 | 125.0 |
| NIAW-2892 | 50.0 | 46.0 | 48.0 | 55.0 | 51.0 | 53.0 | 123.0 | 121.0 | 122.0 |
| HD-2932 | 49.0 | 44.0 | 46.5 | 54.0 | 49.0 | 51.5 | 125.0 | 119.0 | 122.0 |
| DBW-17 | 49.0 | 43.0 | 46.0 | 54.0 | 48.0 | 51.0 | 124.0 | 118.0 | 121.0 |
| HALNA | 50.0 | 45.0 | 47.5 | 55.0 | 50.0 | 52.5 | 123.0 | 120.0 | 121.5 |
| PBW-343 | 56.0 | 53.0 | 54.5 | 61.0 | 58.0 | 59.5 | 131.0 | 127.0 | 129.0 |
| LOK-54 | 54.0 | 49.0 | 51.5 | 59.0 | 54.0 | 56.5 | 129.0 | 123.0 | 126.0 |
| LOK-1 | 55.0 | 48.0 | 51.5 | 60.0 | 53.0 | 56.5 | 130.0 | 122.0 | 126.0 |
| HD-2189 | 51.0 | 44.0 | 47.5 | 57.0 | 49.0 | 53.0 | 126.0 | 119.0 | 122.5 |
| Mean | 50.8 | 46.1 | 48.4 | 55.9 | 51.1 | 53.5 | 125.5 | 120.9 | 123.2 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.16 | 0.21 | 0.59 | 0.19 | 0.25 | 0.72 | 0.16 | 0.21 | 0.59 |
| CD 1% | 0.62 | 0.89 | NS | 0.75 | 1.08 | NS | 0.62 | 0.89 | 2.31 |
| | **Plant height (cm)** | | | **Number of tillers plant$^{-1}$** | | | **Leaf area (dm$^2$ plant$^{-1}$)** | | |
| NIAW-2792 | 71.72 | 68.63 | 70.17 | 2.13 | 2.50 | 2.31 | 3.11 | 3.34 | 3.22 |
| NIAW-2809 | 70.84 | 68.75 | 69.79 | 2.00 | 2.75 | 2.38 | 2.96 | 3.18 | 3.07 |
| NIAW-2837 | 69.39 | 68.30 | 68.84 | 2.25 | 3.25 | 2.75 | 2.59 | 2.77 | 2.68 |
| NIAW-2874 | 69.28 | 67.19 | 68.23 | 1.88 | 2.75 | 2.31 | 2.76 | 2.89 | 2.83 |
| NIAW-2859 | 65.05 | 62.96 | 64.00 | 1.75 | 2.75 | 2.25 | 3.11 | 3.34 | 3.22 |
| NIAW-2891 | 68.03 | 65.94 | 66.98 | 1.25 | 2.25 | 1.75 | 2.74 | 2.80 | 2.77 |
| NIAW-2892 | 70.79 | 63.70 | 67.24 | 1.88 | 2.75 | 2.31 | 2.81 | 2.94 | 2.88 |
| HD-2932 | 73.17 | 71.08 | 72.12 | 1.75 | 2.38 | 2.06 | 2.65 | 2.74 | 2.69 |
| DBW-17 | 71.17 | 69.08 | 70.12 | 1.13 | 2.50 | 1.81 | 2.97 | 3.28 | 3.12 |
| HALNA | 65.84 | 63.75 | 64.79 | 2.00 | 2.75 | 2.38 | 3.26 | 3.51 | 3.38 |
| PBW-343 | 69.49 | 68.40 | 68.94 | 1.75 | 3.25 | 2.50 | 2.73 | 2.92 | 2.82 |
| LOK-54 | 71.43 | 69.34 | 70.38 | 2.00 | 3.00 | 2.50 | 3.12 | 3.35 | 3.24 |
| LOK-1 | 72.94 | 70.85 | 71.89 | 1.75 | 2.88 | 2.31 | 2.94 | 3.06 | 3.00 |
| HD-2189 | 72.77 | 70.68 | 71.72 | 1.88 | 2.75 | 2.31 | 3.01 | 3.15 | 3.08 |
| Mean | 70.13 | 67.76 | 68.95 | 1.81 | 2.75 | 2.28 | 2.91 | 3.09 | 3.00 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.16 | 0.21 | 0.59 | 0.08 | 0.10 | 0.29 | 0.02 | 0.03 | 0.09 |
| CD 1% | 0.62 | 0.89 | 2.32 | 0.30 | NS | NS | 0.09 | 0.13 | NS |

**Effect of temperature regimes on physiological parameters**

The knowledge on physiological understanding in relation to rate of photosynthesis and productivity and wide genetic variability among various traits, as reported in this study, could be utilized in developing new potential germplasm and designing ideotype for making the cultivars more adaptive for different water availability areas in semi-arid tropics Nautiyal *et al*. (2012) [17]. Heat stress reduces photosynthesis through disruptions in the structure and function of chloroplasts, and reductions in chlorophyll content *(*Xu *et al.* 1995) [27]. The differences among temperatures, genotypes and it's interaction were statistically significant for rate of photosynthesis and transpiration, however, significant differences were statistically significant for stomatal conductance among temperatures and genotypes (Table 4).

The higher temperatures at 25/20 $^0$C maintained higher rate of photosynthesis (7.85 µmole $CO_2$ $m^{-1}$ $s^{-1}$), transpiration (4.65 mmole $H_2O$ $m^{-1}$ $s^{-1}$) and stomatal conductance (0.16 µmole $CO_2$ $m^{-1}$ $s^{-1}$) than lower temperature at 20/15$^0$C. The genotypes, NIAW-2792 (7.62 µmole $CO_2$ $m^{-1}$ $s^{-1}$), NIAW-2809 (7.50 µmole $CO_2$ $m^{-1}$ $s^{-1}$), NIAW-2837 (7.34 µmole $CO_2$ $m^{-1}$ $s^{-1}$) and PBW-343 (7.33 µmole $CO_2$ $m^{-1}$ $s^{-1}$) for rate of photosynthesis, HD-2189 (4.68 mmole $H_2O$ $m^{-1}$ $s^{-1}$), NIAW-2892 (4.63 mmole $H_2O$ $m^{-1}$ $s^{-1}$), NIAW-2891 (4.61 mmole $H_2O$ $m^{-1}$ $s^{-1}$) and NIAW-2809 (4.54 mmole $H_2O$ $m^{-1}$ $s^{-1}$) for transpiration rate and NIAW-2837, NIAW-2891, HD-2932 and HD-2189 (0.16 µmole $CO_2$ $m^{-1}$ $s^{-1}$) were found promising for related characters.

Wheat is a thermo-sensitive long-day crop requires relatively low temperature for satisfactory growth and high temperature is a major determinant of its growth and productivity. In wheat, mean maximum temperature during grain development between 25 to 32˚C is considered moderately high temperature and 35 to 40˚C is considered very high temperature (Stone and Nicholas 1995) [26]. The optimum leaf temperature for photosynthesis from the response of the wheat genotypes was found to be 26 ˚C, decline in carboxylation efficiency with leaf temperature above 26 ˚C. Optimal temperature range between 21 ˚C and 32 ˚C were also observed by Bunce (2000) [8]. Canopy temperature depression and leaf conductance show an association with each other and with yield (Amani *et al*. 1996) [3].

The canopy temperature was statistically significant among temperatures, while it was non-significant among genotypes and it's interaction effect. However, the canopy temperature depression (CTD) was statistically non-significant among temperatures, genotypes and it's interaction effects (Table 4). The temperature at 20/15$^0$C maintained lower canopy temperature (17.25$^0$C) and higher CTD (-0.91$^0$C) than elevated temperature at 25/20$^0$C (22.34 & -0.75$^0$C). The genotypes, HD-2189 (19.18$^0$C), PBW-343 (19.13$^0$C) and (19.05$^0$C) recorded minimum canopy temperature, whereas, LOK-1 (-1.30$^0$C), NIAW-2792 (-1.20$^0$C) and NIAW-2874 (-1.15$^0$C) maintained the higher CTD. The chlorophyll content (SPAD index) was statistically significant among temperatures and genotypes, however, it was non-significant among it's interaction effect. The temperatures at 25/20$^0$C (42.00) recorded the higher SPAD index than lower temperature at 20/15$^0$C (37.70). The genotypes, NIAW-2792 (42.53), NIAW-2837 (42.45), HALNA (41.43) and NIAW-2809 (41.35) recorded the higher SPAD index for chlorophyll content (Table 5). During the grain filling period high temperature decreases leaf chlorophyll content and accelerates senescence (Yang *et al*. 2002 and Zhao *et al*. 2007) [29, 30] leading to a shorter grain filling duration with an ultimate decrease in individual grain weight and yield (Gibson and Paulsen 1999 and Altenbach *et al*. 2003) [12, 2].

**Table 4:** Physiological parameters as influenced by wheat genotypes under various temperature regimes

| Genotypes | 20/15$^0$C | 25/20$^0$C | Mean | 20/15$^0$C | 25/20$^0$C | Mean | 20/15$^0$C | 25/20$^0$C | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | Rate of photosynthesis (µmole $CO_2$ $m^{-1}$ $s^{-1}$) | | | Transpiration rate (mole $H_2O$ $m^{-1}$ $s^{-1}$) | | | Stomatal conductance (µmole $CO_2$ $m^{-1}$ $s^{-1}$) | | |
| NIAW-2792 | 6.95 | 8.29 | 7.62 | 3.43 | 4.76 | 4.09 | 0.13 | 0.17 | 0.15 |
| NIAW-2809 | 6.93 | 8.08 | 7.50 | 4.48 | 4.60 | 4.54 | 0.15 | 0.15 | 0.15 |
| NIAW-2837 | 6.32 | 8.36 | 7.34 | 3.65 | 4.39 | 4.02 | 0.15 | 0.17 | 0.16 |
| NIAW-2874 | 6.63 | 8.01 | 7.32 | 4.25 | 4.63 | 4.44 | 0.15 | 0.16 | 0.15 |
| NIAW-2859 | 5.65 | 7.85 | 6.75 | 4.05 | 4.14 | 4.09 | 0.14 | 0.16 | 0.15 |
| NIAW-2891 | 5.71 | 6.75 | 6.23 | 4.49 | 4.73 | 4.61 | 0.15 | 0.16 | 0.16 |
| NIAW-2892 | 5.58 | 7.60 | 6.59 | 4.21 | 5.05 | 4.63 | 0.16 | 0.17 | 0.16 |
| HD-2932 | 6.14 | 8.28 | 7.21 | 3.57 | 4.68 | 4.12 | 0.14 | 0.15 | 0.15 |
| DBW-17 | 6.38 | 7.69 | 7.03 | 3.88 | 5.03 | 4.45 | 0.14 | 0.15 | 0.14 |
| HALNA | 6.47 | 7.59 | 7.03 | 3.25 | 4.07 | 3.66 | 0.14 | 0.13 | 0.13 |
| PBW-343 | 6.38 | 8.28 | 7.33 | 3.48 | 5.14 | 4.31 | 0.15 | 0.15 | 0.15 |
| LOK-54 | 6.58 | 7.63 | 7.10 | 3.48 | 4.33 | 3.91 | 0.14 | 0.16 | 0.15 |
| LOK-1 | 6.23 | 7.28 | 6.75 | 3.79 | 4.16 | 3.97 | 0.14 | 0.15 | 0.15 |
| HD-2189 | 6.00 | 8.29 | 7.14 | 3.90 | 5.46 | 4.68 | 0.15 | 0.16 | 0.16 |
| Mean | 6.28 | 7.85 | 7.07 | 3.85 | 4.65 | 4.25 | 0.15 | 0.16 | 0.15 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.02 | 0.03 | 0.07 | 0.02 | 0.03 | 0.09 | 0.001 | 0.002 | 0.005 |
| CD 1% | 0.07 | 0.11 | 0.28 | 0.09 | 0.13 | 0.34 | 0.005 | 0.007 | NS |
| | **Canopy temperature ($^0$C)** | | | **CTD ($^0$C)** | | | **Chlorophyll content (SPAD)** | | |
| NIAW-2792 | 17.70 | 23.10 | 20.40 | -1.55 | -0.85 | -1.20 | 40.10 | 44.95 | 42.53 |
| NIAW-2809 | 17.40 | 22.60 | 20.00 | -0.45 | -1.05 | -0.75 | 38.95 | 43.75 | 41.35 |
| NIAW-2837 | 17.80 | 23.30 | 20.55 | -0.50 | -0.55 | -0.53 | 40.40 | 44.50 | 42.45 |
| NIAW-2874 | 17.00 | 22.65 | 19.83 | -1.40 | -0.90 | -1.15 | 36.15 | 41.20 | 38.68 |
| NIAW-2859 | 17.50 | 22.35 | 19.93 | -0.60 | -0.75 | -0.68 | 38.05 | 41.80 | 39.93 |
| NIAW-2891 | 16.80 | 22.65 | 19.73 | -0.40 | -0.65 | -0.53 | 36.20 | 38.85 | 37.53 |
| NIAW-2892 | 16.85 | 21.25 | 19.05 | -1.35 | -0.75 | -1.05 | 38.30 | 41.15 | 39.73 |
| HD-2932 | 17.50 | 22.85 | 20.18 | -1.15 | -0.80 | -0.98 | 38.05 | 43.50 | 40.78 |
| DBW-17 | 17.60 | 22.65 | 20.13 | -0.65 | -0.80 | -0.73 | 37.55 | 42.10 | 39.83 |
| HALNA | 16.90 | 22.20 | 19.55 | -0.85 | 0.00 | -0.43 | 38.90 | 43.95 | 41.43 |
| PBW-343 | 16.75 | 21.50 | 19.13 | -0.90 | -0.75 | -0.83 | 36.35 | 41.35 | 38.85 |
| LOK-54 | 17.30 | 22.55 | 19.93 | -0.70 | -0.80 | -0.75 | 34.55 | 39.10 | 36.83 |
| LOK-1 | 17.15 | 22.05 | 19.60 | -1.35 | -1.25 | -1.30 | 36.25 | 39.90 | 38.08 |
| HD-2189 | 17.30 | 21.05 | 19.18 | -0.90 | -0.65 | -0.78 | 37.95 | 41.95 | 39.95 |
| Mean | 17.25 | 22.34 | 19.80 | -0.91 | -0.75 | -0.83 | 37.70 | 42.00 | 39.85 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.15 | 0.20 | 0.55 | 0.07 | 0.09 | 0.26 | 0.26 | 0.35 | 0.99 |
| CD 1% | 0.58 | NS | NS | NS | NS | NS | 1.03 | 1.49 | NS |

**Effect of temperature regimes on biochemical and yield parameters:** The generative growth constitutes the development and growth of reproductive parts. From yield point of view, this phase assumes significance as the sink lies in the reproductive parts. Hence, the detailed observations were made on various aspects of yield contributing characters at the stage of maturity. The yield loss of wheat in India due to rising temperature has been projected as 4-5 million tons per year with every degree rise of temperature throughout the growing period even after considering the benefits of carbon fertilization (Aggarwal 2007) [1], decreasing yields by 3 to 5% per 1$^{\circ}$C increase above normal conditions (Gibson and Paulsen 1999) [12]. The differences among temperature treatments were statistically significant, however it is non-significant among the genotypes and it's interaction for panicles plant$^{-1}$ (Table 5). The temperature treatment 25/20 $^0$C produced higher panicles plant$^{-1}$ (2.75) than 20/15 $^0$C (1.81). The genotypes, NIAW-2837 (2.75), PBW-343 and LOK-54 (2.50 produced significantly while higher mean number of panicles plant$^{-1}$. These genotypes also maintained higher number of panicles plant$^{-1}$ at 25/20$^0$C. The differences among temperatures, genotypes and its interaction were statistically significant for grains plant$^{-1}$ and grain yield plant$^{-1}$. The temperature treatment 25/20$^0$C (85.02) maintained significantly higher grains plant$^{-1}$ over 20/15$^0$C (63.14). The genotypes, NIAW-2837 (82.75), NIAW-2809 (80.84), NIAW-2874 (79.28), LOK-54 (79.15) recorded higher, while HALNA (61.75) genotype gave lower grains plant$^{-1}$. The interaction of NIAW-2837 with 25/20$^0$C (96.80) produced higher and HALNA at 20/15$^0$C (50.45) regime gave least grains plant$^{-1}$. The temperature treatment 25/20$^0$C (3.56 g) recorded the higher yield plant$^{-1}$ over 20/15$^0$C (2.37g). The genotypes, NIAW-2809 (3.50 g), NIAW-2874 (3.28 g), NIAW-2859 (3.24 g) and NIAW-2837 (3.19 g) recorded higher and NIAW-2792 (2.44 g) and HALNA (2.45g) recorded lower yield plant$^{-1}$. Among the interactions, NIAW-2809 (4.31 g), NIAW-2859 (4.09 g) and NIAW-2837 (40.1 g) maintained the highest grain yield plant$^{-1}$ at 25/20 $^0$C. Rahman *et al*. (2005) [21] reported that higher temperature (30/20°C, day/night) induced significant reduction of final grain weight, grain growth rate and grain growth duration of wheat as compared to optimum temperature (25/15 °C, day/night). The differences among temperature treatments were statistically significant, however it was non-significant among the genotypes and it, s interaction for harvest index. The temperature treatment 25/20 $^0$C (45.46%) showed the higher harvest index than at 20/15 $^0$C (38.13%). The genotypes, NIAW-2809 (46.02 %), LOK-54 (44.14%), NIAW-2891 (44.08%) and NIAW-2874 (44.00%) recorded the higher harvest index.

Heat stress leads to drastic change in the cell membrane stability and ultimately influences the sensors present in the membrane. Most of the earlier studies on the effects of multitude of abiotic stresses showed changes in the level of several physiological parameters including lipid peroxidation, $H_2O_2$ production and proline accumulation in wheat. Proline has a role in the protection of plants by acting as a cellular osmotic regulator between cytoplasm and vacuole. The differences among temperature treatments, genotypes and it's interaction were statistically significant for proline content and lipid peroxidation rate (Table 5). The temperature treatment at 25/20 $^0$C showed the higher proline content (1.81 µmoles/g) over 20/15 $^0$C (0.84 µmoles/g). The genotype NIAW-2837 recorded the higher proline content (1.64 µmoles/g) and it was at par with NIAW-2809 (1.46 µmoles/g) and HD-2189 (1.46 µmoles/g), while it was less in NIAW-2892 (1.07 µmoles/g). The genotypes, HD-2189 (2.31 µmoles/g), NIAW-2837 (2.04 µmoles/g), NIAW-2809 (2.02 µmoles/g), NIAW-2874 (2.01 µmoles/g) and PBW-343 (2.01) maintained the higher proline content under elevated temperature. It indicated that these genotypes were tolerant to thermal stress.

**Table 5:** Yield components and biochemical characters as influenced by wheat genotypes under various temperature regimes

| Genotypes | 20/15$^0$C | 25/20$^0$C | Mean | 20/15$^0$C | 25/20$^0$C | Mean | 20/15$^0$C | 25/20$^0$C | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | **Number of panicles plant$^{-1}$** | | | **Number of grains plant$^{-1}$** | | | **Grain yield (g plant$^{-1}$)** | | |
| NIAW-2792 | 2.13 | 2.50 | 2.31 | 64.75 | 78.68 | 71.71 | 1.78 | 3.10 | 2.44 |
| NIAW-2809 | 2.00 | 2.75 | 2.38 | 65.38 | 96.30 | 80.84 | 2.70 | 4.31 | 3.50 |
| NIAW-2837 | 2.25 | 3.25 | 2.75 | 68.70 | 96.80 | 82.75 | 2.36 | 4.01 | 3.19 |
| NIAW-2874 | 1.88 | 2.75 | 2.31 | 71.75 | 86.80 | 79.28 | 2.95 | 3.61 | 3.28 |
| NIAW-2859 | 1.75 | 2.75 | 2.25 | 57.50 | 94.80 | 76.15 | 2.38 | 4.09 | 3.24 |
| NIAW-2891 | 1.25 | 2.25 | 1.75 | 42.50 | 72.55 | 57.53 | 2.45 | 3.31 | 2.88 |
| NIAW-2892 | 1.88 | 2.75 | 2.31 | 54.13 | 81.18 | 67.65 | 2.13 | 3.38 | 2.75 |
| HD-2932 | 1.75 | 2.38 | 2.06 | 59.25 | 82.18 | 70.71 | 2.45 | 3.42 | 2.94 |
| DBW-17 | 1.13 | 2.50 | 1.81 | 59.38 | 78.68 | 69.03 | 2.03 | 3.29 | 2.66 |
| HALNA | 2.00 | 2.75 | 2.38 | 50.45 | 73.05 | 61.75 | 1.80 | 3.09 | 2.45 |
| PBW-343 | 1.75 | 3.25 | 2.50 | 62.38 | 88.68 | 75.53 | 2.58 | 3.51 | 3.04 |
| LOK-54 | 2.00 | 3.00 | 2.50 | 66.50 | 91.80 | 79.15 | 2.50 | 3.81 | 3.16 |
| LOK-1 | 1.75 | 2.88 | 2.31 | 66.50 | 87.55 | 77.03 | 2.30 | 3.61 | 2.96 |
| HD-2189 | 1.88 | 2.75 | 2.31 | 66.75 | 81.30 | 74.03 | 2.75 | 3.29 | 3.02 |
| Mean | 1.81 | 2.75 | 2.28 | 61.14 | 85.02 | 73.08 | 2.37 | 3.56 | 2.96 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.08 | 0.10 | 0.29 | 0.67 | 0.89 | 2.51 | 0.04 | 0.05 | 0.15 |
| CD 1% | 0.30 | NS | NS | 2.62 | 3.78 | 9.80 | 0.15 | 0.22 | 0.57 |
| | **Harvest index (%)** | | | **Proline content (µmoles/g fresh weight)** | | | **Lipid peroxidation rate (µmoles MDA /g fresh weight)** | | |
| NIAW-2792 | 24.34 | 40.76 | 32.55 | 0.88 | 1.63 | 1.25 | 22.93 | 46.71 | 34.82 |
| NIAW-2809 | 40.41 | 51.63 | 46.02 | 0.90 | 2.02 | 1.46 | 22.16 | 45.89 | 34.02 |
| NIAW-2837 | 36.72 | 48.05 | 42.39 | 1.25 | 2.04 | 1.64 | 23.45 | 37.89 | 30.67 |
| NIAW-2874 | 40.37 | 47.64 | 44.00 | 0.80 | 2.01 | 1.40 | 14.16 | 37.12 | 25.64 |
| NIAW-2859 | 37.75 | 49.48 | 43.62 | 0.87 | 1.51 | 1.19 | 24.74 | 45.12 | 34.93 |
| NIAW-2891 | 42.64 | 45.52 | 44.08 | 0.82 | 1.60 | 1.21 | 20.87 | 45.50 | 33.18 |
| NIAW-2892 | 33.68 | 47.20 | 40.44 | 0.88 | 1.26 | 1.07 | 19.83 | 48.21 | 34.02 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HD-2932 | 37.51 | 44.81 | 41.16 | 0.72 | 1.96 | 1.34 | 27.32 | 32.48 | 29.90 |
| DBW-17 | 36.75 | 40.86 | 38.80 | 0.58 | 1.77 | 1.17 | 20.61 | 22.16 | 21.38 |
| HALNA | 40.81 | 42.35 | 41.58 | 0.81 | 1.49 | 1.15 | 30.15 | 36.09 | 33.12 |
| PBW-343 | 40.81 | 40.69 | 40.75 | 0.89 | 2.01 | 1.45 | 20.87 | 39.44 | 30.15 |
| LOK-54 | 41.82 | 46.45 | 44.14 | 0.92 | 1.90 | 1.41 | 19.83 | 47.96 | 33.90 |
| LOK-1 | 38.96 | 45.98 | 42.47 | 0.77 | 1.90 | 1.34 | 27.32 | 47.24 | 37.28 |
| HD-2189 | 41.22 | 45.06 | 43.14 | 0.62 | 2.31 | 1.46 | 20.61 | 33.51 | 27.06 |
| Mean | 38.13 | 45.46 | 41.80 | 0.84 | 1.81 | 1.33 | 22.49 | 40.38 | 31.43 |
| | **E** | **G** | **G x E** | **E** | **G** | **G x E** | **E** | **G** | **G x E** |
| S.Em(±) | 0.87 | 1.14 | 3.24 | 0.04 | 0.05 | 0.13 | 0.27 | 0.36 | 1.02 |
| CD 1% | 3.38 | NS | NS | 0.14 | 0.20 | 0.51 | 1.07 | 1.54 | 3.99 |

The temperature at 20/15$^0$C showed decline in mean lipid peroxidation rate (22.49 nmoles MDA/g) over the 25$^0$C regime (40.388 nmoles MDA/g). The genotype LOK-1 showed higher mean lipid peroxidation rate (37.28 nmoles MDA/g), while DBW-17 gave less lipid peroxidation rate (21.38 nmoles MDA/g). The genotypes, DBW-17 (22.16 nmoles MDA/g), HD-2189 (33.51 nmoles MDA/g), HALNA (36.09 nmoles MDA/g) and NIAW-2874 (37.12) at elevated temperature recorded less peroxidation rate. Therefore these genotypes were found tolerant to thermal stress. Kumar *et al*. (2012) reported that plant metabolites in complex biosynthetic pathways are believed to be affected by terminal heat stress.

The 15/15$^0$C temperature favours for 100% germination and better germination properties, where as, 20/20$^0$C and 25/15$^0$C found good for optimum germination and seedling growth characters in chickpea. The genotypes, LOK-54, LOK-1, DBW-17 and HALNA were promising for germination percentage, promptness index, mean germination time and coefficient of germination velocity. The genotypes, NIAW-2874, NIAW-2892, NIAW-2837 and PBW-343 performed better for seedling growth. The genotypes, HALNA, LOK-1, PBW-343 and HD-2189 were better for maintaining least relative saturation deficit.

The elevated temperature at 25/20$^0$C had earlier initiation of flowering, 50 % flowering and maturity, arrested plant growth, profuse tillering, higher leaf area, rate of photosynthesis, transpiration, stomatal conductance, canopy temperature, chlorophyll content, lower canopy temperature depression and higher proline content and higher lipid peroxidation rate than lower temperature at 20/15$^0$C. The genotypes, NIAW-2809, NIAW-2874, DBW-17 and HALNA were found early for initiation of flowering, 50 % flowering and maturity, whereas, LOK-54, NIAW-2792, HD-2189 and HALNA were promising for plant height, number of tillers and leaf area plant$^{-1}$.

The genotypes, NIAW-2792, NIAW-2809, NIAW-2837 and PBW-343 for higher rate of photosynthesis; HD-2189, NIAW-2892, NIAW-2891 and NIAW-2809 for higher transpiration rate; NIAW-2837, NIAW-2891, HD-2932 and HD-2189 for higher stomatal conductance; HD-2189 and PBW-343 for minimum canopy temperature; LOK-1, NIAW-2792 and NIAW-2874 for higher CTD and NIAW-2792, NIAW-2837, HALNA and NIAW-2809 for higher SPAD index were promising for related aspects. The genotypes, HD-2189, NIAW-2837, NIAW-2809, NIAW-2874, PBW-343, DBW-17 and HALNA maintained higher proline content and lower lipid peroxidation rate. The elevated temperature at 25/20$^0$C maintained higher number of panicles plant$^{-1}$, grains plant$^{-1}$, grain yield (g plant$^{-1}$) and harvest index (%) than lower temperatures at 20/15$^0$C.The genotypes, NIAW-2809, NIAW-2874, NIAW-2859 and NIAW-2837 recorded the higher grain yield plant by maintaining higher number of panicles plant$^{-1}$, grains plant$^{-1}$ and harvest index.

On the basis of relative ranking, the 15/15$^0$C temperature favours for 100% germination and better germination properties, whereas, 20/20$^0$C and 25/15$^0$C found good for optimum germination and seedling growth characters in wheat. The 25/20$^0$C temperature was found better for earlier crop phenology, better vegetative growth, physiological parameters, biochemical characters and yield and yield contributing characters. The genotypes, LOK-54, LOK-1, DBW-17 and HALNA were superior for maintaining better germination and it's properties, however, NIAW-2874, NIAW-2892, NIAW-2837 and PBW-343 were good for seedling growth. As per the comparison between lower and elevated temperatures, NIAW-2809, NIAW-2874, NIAW-2859 and NIAW-2837 were found superior at elevated temperature for better vegetative growth, physiological parameters, biochemical characters and yield and yield contributing characters. Therefore, these genotypes might be considered for further breeding programme for crop improvement in wheat at elevated temperature regime.

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