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Physiological Responses of Wheat Associate with Heat Tolerance

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study was performed to explore heat stress tolerance indices to judge terminal heat tolerance genotypes from nine wheat genotypes viz: AKAW 5023, AKAW 4927, PBN 4905, PBN 4751-02, NIAW 3523, NIAW 2891, AKAW 4210-6 (C), NIAW 34 (C), NIAW 1994 (C) at Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MH) during Rabi 2016-17 and 2017-2018. The trial was setup in RBD design with three replications. Yield and Physiological traits were recorded and correlated with yield. Genotype NIAW 2891 noted significantly high germination %,CTD (4.30oC), minimum membrane thermo-stability index (48.86%) at 75 DAS (grain filling stage), exhibited more RGR (0.0074 g g-1 day-1), NAR (0.0500 g dm2 day-1), early 50% flowering (58.16 days), days to maturity (91.83 days) and more grain yield ha-1 (35.65 q/ha) followed by genotype NIAW 3523 (33.83 q/ha) during both the year and noted as heat tolerance genotypes against the best check AKAW 4210-6. Correlation analysis showed that yield under stress environment had positive significant correlate with days to 50 % flowering and physiological maturity however, canopy temperature and membrane thermo-stability index had negative significant correlation with yield. Hence, due emphasis should be given to these attributes for genetic improvement in wheat under heat stress condition.

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Keywords: Wheat; heat stress condition; CTD; MTSI; RGR; NAR; 50% flowering; maturity.

1. INTRODUCTION

"Wheat (*Triticum aestivum L*.) is one of the most widely cultivated cereal crops in the world, making a significant contribution to global cereal production (28%) and trade (41.5%)" [1]. "About 198 million tonnes of additional wheat grain will be required to feed the increasing human population predicted to be 9.8 billion by 2050" [2]. "Wheat production is vulnerable to abiotic and biotic stresses with a stagnant or declining rates of productivity across the globe" [3]. "Different climatic factors interact spatiotemporally and influence crop growth and production. To better cope with the climatic variables (e.g., temperature and rainfall), their impacts must be quantified and understood. The adverse impact of heat stress (HS) induced through rising ambient temperature and unpredictable climatic variations is clear and threatening wheat production in all ecologies (temperate, subtropical and in tropical)" [4].

"The mean global temperature of the Earth is expected to increase by 1.5°C within the next two decades" [5]. "Recent analysis from scientific communities, including the Goddard Institute for Space Studies (GISS), indicated an increase in average global temperature of 1.04°C from 1880 to 2019" (NOAA, 2020). "This elevated temperature is causing heat stress (HS) that triggers significant changes in the biological and developmental process of wheat, leading to a reduction in grain production and grain quality" [6]. "In India alone around 13.5 million hectares of wheat is heat stressed" [7]. During past few years, more than 50% sowing of wheat often gets delayed till December or early January causing substantial loss in grain yield.

In Maharashtra, the life cycle of the wheat crop covers a period from October-November to March-April during which thermal and photo period undergo gradual changes. During vegetative phase the temperature ranges from 35.2^0C down to 20^0C maximum and 17.1 to 6.6^0C minimum. Under this thermal regime, the wheat plant completes its vegetative phase and switches over to reproductive phases and important physiological changes occur during this period. Under Akola condition clear sky facilitates maximum radiation in day and rapid loss of heat in nights resulting in high diurnal fluctuations in temperature range from 35^0C to 17^0C. Solar radiation incident on leaf surface and soil surface increases air, leaf and soil temperature.

"January causing substantial loss in grain yield. Amongst several constraints which affects wheat productivity, delayed sowing ranks at the top as it exposes the crop to high temperature stress at anthesis / grain filling stage. The effective development of plant parts are pre-requisite for better expression of inherent potential and better utilization of environmental variables. Extensive studies have demonstrated that at post-anthesis temperature stress results in early senescence and more mobilization of pre-anthesis stored assimilates to grain in cereals. Growth of kernels reduces depending upon the degree of stresses and thereby limiting final grain yield" [8,9]. "The reduction was found to be more severe when the stress occurred suddenly rather than gradually and at early stage of grain filling than at later stages" [10]. "Higher temperature enhances leaf senescence causing reduction in green leaf area during reproductive stage and alters photosynthate partitioning to economic products. The rapid leaf senescence ultimately resulted in less productive tillers per plant, which is one of the major causes of yield loss of wheat. However, crop response to high temperature varied with variation of temperature, duration of exposure, crop growth stages and also due to the level of crop tolerance" [11,12]. There are several major aspects of thermo-tolerance from the physiological and biochemical levels, the relation to membrane stability, and productivity during high temperature stress. Physiological traits that are associated with yield in heat prone environments are canopy temperature depression, membrane thermostability and leaf chlorophyll content during grain filling, photosynthesis and senescence.

2. MATERIALS AND METHODS

The study was carried out during 2016-17 and 2017-18 wheat season in the research field of Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola (M.S). "Akola is situated in the subtropical zone at the latitude of 200 42' North and longitude of 770 02' East. Altitude of the place is 307.41 m above the mean sea level. Treatments were 9 wheat genotypes (AKAW 5023, AKAW 4927, PBN 4905, PBN 4751-02, NIAW 3523, NIAW 2891, AKAW 4210-6 (C), NIAW 34 (C), NIAW 1994 (C) sown on late (December 1-10) condition in randomized block design with three replications. For late-sown conditions, management and inputs were same except the seeding date. Each unit plot size was

Gross - 6.0 m × 2.16 m (12 rows) and net plot size 6.0 m × 1.80 m (10 Middle rows) length of each. Seeds were sown continuously in rows 18 cm apart at a seed rate of 125 kg ha^{-1}. Recommended fertilizer doses 90:60:40 NPK kg ha^{-1} were applied respectively. Half N and a complete dose of P_2O_5 and K_2O were given as a basal dose at sowing while the remaining N was applied 18 days after sowing. A uniform pre-sowing soaking irrigation was given to all the plots during both the experiments. In all, the crop received seven to eight need based irrigations at different critical growth stages. Intercultural operations were done properly as per WRC recommendation and when necessary. Statistical analysis was done by employing standard statistical methods for randomized block design as suggested by Panse and Sukhatme [13] and correlation analysis was done as per the formula suggested by Karl Pearson's correlation coefficient" [14].

2.1 Canopy Temperature and Canopy Temperature Depression (Δ^{0}C)

Canopy temperature depression (CTD) was calculated using the following formula provided by Rosyara [15].

Canopy temperature depression (CTD) = Ambient temperature. (Air temperature) - Canopy Temperature.

2.2 Membrane Thermo-Stability Index (%)

Membrane stability index was calculated as per the following formula suggested by Kushwaha et al. [16].

Membrane stability index = 1 – (C_1/C_2) x 100

C_1 = Electrical conductivity at 50 ^{0}C
C_2 = Electrical conductivity at 100 ^{0}C

2.3 Relative Growth Rate (RGR)

RGR was calculated as suggested by Fisher [17].

$$RGR = \frac{\text{Log e } W_2 - \text{Log e } W_1}{t_2 - t_1} \text{ g g}^{-1}\text{ day}^{-1}$$

Where,

Log e = Natural logarithms

W_1 and W_2 = weight of plant at time (days) t_1 and t_2, respectively.

RGR was calculated for the period in between 30-45, 45-60 and 60-75 DAS for both the years under late sown heat stress conditions.

2.4 Net Assimilation Rate (NAR)

Calculated for the period in between 30-45, 45-60 and 60-75 DAS as per the formula provided by Williams (1946).

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Log e } LA_2 - \text{Log e } LA_1}{LA_2 - LA_1} \text{ g dm}^{-2}\text{day}^{-1}$$

Where,

LA_1 and LA_2 = Leaf area (dm^2)
W_1 and W_2 = Total dry weight of a plant (g) at time interval
t_1 and t_2 (days) respectively.
Log e = Natural logarithms

3. RESULTS AND DISCUSSION

3.1 Canopy Temperature and Canopy Temperature Depression (Δ^{0}C)

Mean canopy temperature increased by 4.12°C, 6.2°C. 4.28°C from 30-45. 45-60 and 60-75 DAS. It indicates high temperature stress was severe at anthesis and post anthesis stage. CT values were 25.34°C and 25.18°C at 60 DAS (anthesis) and 30.94°C and 31.87°C at 75 DAS (grain filling stage) under heat stress condition which resulted into higher yield. Genotypes *viz*., NIAW 2891 (30.94^0 C), NIAW 3523 (31.87°C) and AKAW 5023 (32.39^0 C) maintained cooler canopy by exhibiting significantly lower CT than the best check AKAW 4210-6 (33.49^{0}C) whereas genotype PBN 4905 (35.02^{0}C) recorded highest canopy temperature and the mean reduction was 0.45% in second year over the first year.

Plant potential to keep their canopy cool is one of the important traits of high temperature tolerant wheat genotypes. This is reflected by canopy temperature depression (CTD). "Higher canopy temperature increase transpiration by changing vapour pressure deficit at leaf surface and secondly may lead to enhanced ageing of foliage and shortening of growing season i.e. grain filling duration" [18].

Overall canopy temperature depression was higher at 30 and 45 days after sowing and decreased thereafter, at 60 and 75 days after sowing (post anthesis). At 60 days after sowing, the maximum value of CTD was observed up to 7.13° C. Among the genotypes, NIAW 2891 (4.30°C) and NIAW 3523 (3.36°C) exhibited significantly higher value of CTD when compared with superior check AKAW 4210-6 (1.74°C). However, genotypes PBN 4751-02 (1.0°C), AKAW 4927 (0.85°C) and PBN 4905 (0.34°C) recorded significantly lowest CTD than rest of the genotypes when compared with best check AKAW 4210-6 (1.74°C) under heat stress condition.

Canopies may be cooler because of their ability to transfer relatively more heat back to the atmosphere by reflection and convection. Saxena et. al. [19] inferred that, CTD was greater under TS as compared to LS conditions and exhibited higher CTD under LS condition among all the genotypes.

3.2 Membrane Thermo-Stability Index (%) (MST)

Membrane thermo-stability index was found to be more at anthesis stage (60 DAS) and reduced during the grain filling stage at 75 DAS. High yielding wheat genotype NIAW 2891(56.14 and 48.86 %) and NIAW 3523 (56.33 and 49.81) recorded relatively less MSI at anthesis stage and optimum MSI at grain filling stage compared to other wheat genotypes. Highest MSI was recorded in genotype PBN 4905 (73.95 and 64.10 % respectively).

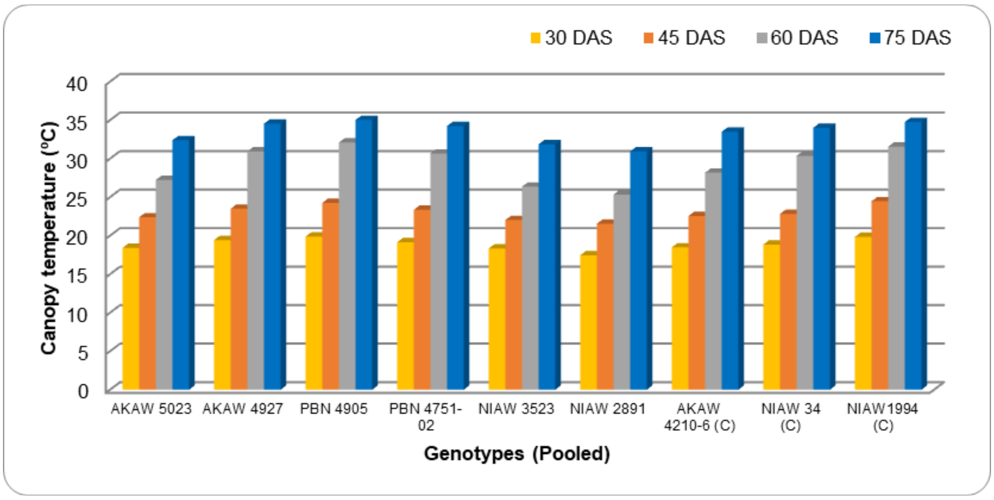

Fig. 1. Canopy temperature

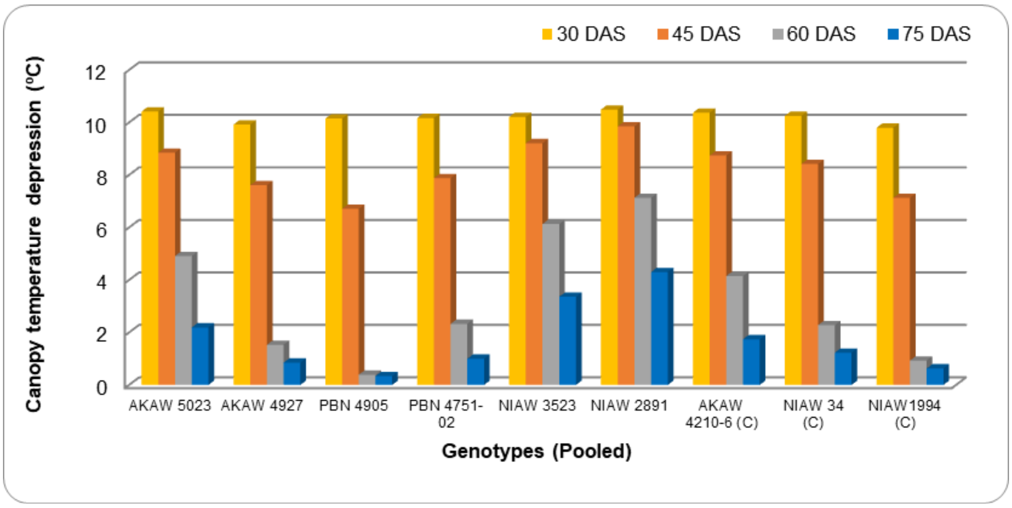

Fig. 2. Canopy temperature depression

Miller et al. [20] revealed that heat stress induced oxidative stress was observed to damage membrane properties, protein degradation, and enzyme deactivation in wheat that reduced the cell viability remarkably. Also significantly increased the membrane peroxidation and increase the membrane thermo-stability by 28% and 54% which surprisingly increased electrolyte leakage in wheat.

3.3 Relative Growth Rate (RGR)

Relative growth rate plant^{-1} in between 45-60 DAS was found maximum under heat stress condition (0.114 g g^{-1} d^{-1}). Genotype AKAW 5023 (0.119 g g^{-1} d^{-1}) was found significantly better at 45-60 DAS. Maximum RGR (0.0074 g g^{-1} d^{-1}) was recorded by both NIAW 2891 and NIAW 3523 under heat stress conditions. Haider [21] reported similar findings and stated that RGR was relatively higher in early sown plants than that of late sown plant in wheat.

3.4 Net Assimilation Rate (NAR)

NAR plant^{-1} increased slowly up to 30-45 and hereafter increased rapidly up to 60-75 DAS in case of high temperature stress NAR increased maximum in 45-60 DAS and decreased gradually up to 60-75 DAS. Significantly superior net assimilation rate were found in genotypes NIAW 2891 (0.0500 g dm^{-2} d^{-1}) and NIAW 3523 (0.0441 g dm^{-2} d^{-1}) as compared to superior check AKAW 4210-6 (0.0387 g dm^{-2} d^{-1}) and lowest value recorded in genotypes AKAW 4927 (0.0316 g dm^{-2} d^{-1}) and PBN 4905 (0.0252 g dm^{-2} d^{-1}). About 0.59 % reduction was observed in second year as compared to first year.

NAR of all the varieties showed decreasing tendency towards the last one stage (60-75 DAS) under late sown condition which might be due to leaf shading and increasing of older dried leaves as well as crop attaining to maturity due to high temperature 36/17.56^{0}C. “Heat imposes negative impacts on leaf of plant like reduced leaf water potential, leaf area and pre-mature leaf senesces which have negative impacts on total photosynthesis performance of plant” [22].

3.5 Days to 50% Anthesis

Days to 50% anthesis occurred 0.96 days earlier due to late sowing (60.70 days) in first year relative to second year (61.66 days) in wheat. Days to 50% anthesis were reduced by 1.21 % due to high temperature stress induced by late sowing. Maximum days required for 50% anthesis were observed in PBN 4751-02 (61.83 days) and AKAW 3523 (61 days) and found *at par* with best check AKAW 4210-6 (61.33 days). Significantly minimum days were required for 50% anthesis in genotypes *viz*., NIAW 2891 (58.16 days), AKAW-4927 (58.66 days), AKAW 5023 (59.16 days) and PBN 4905 (59.33 days). Hussain et al. [23] stated that after emergence and tillering, the late planted crop took less time to switch into further phenophases due to existing high temperature and longer photoperiod.

3.6 Days to Maturity

Significantly maximum days were required from sowing to maturity under heat stress condition (101.40 days) in first year relative to second year (98.85 days). High temperature stress induced by late sowing caused reduction by 2.55 days (2.43%) for days to maturity in second year when compared with first year. NIAW 2891 (91.83 days) and AKAW 5023 (98.83) indicating their earliness. Genotype PBN 4751-02 (100.33 days), NIAW 3523 (100.16 days) and AKAW 4927 (100 days) taken maximum days to complete their life cycle when compared with best check.

It would thus be seen that sowing date influence was of greater order on the post flowering period as compared to pre heading period as it clearly seen by increased average temperature of 0.18^{0}C in second year (34.17/17.83^{0}C) compared to first year (34.45/15.81^{0}C) during reproductive growth period from 50% flowering to maturity. Thus duration required for days to maturity was reduced in all genotypes in second season as compared first season. Similar result have been showed by Kumar et al. [24] stated that the late sown wheat genotypes had matured 15 days earlier than timely sown.

3.7 Grain Yield

Top ranking genotype NIAW 2891 has recorded significantly highest grain yield of 35.65 qt ha^{-1} followed by NIAW 3523 (33.83 qt. ha^{-1}) over superior check AKAW 4210-6 (29.55 ha^{-1}) and among all the genotypes tested. Genotypes AKAW 5023 (31.41 qt. ha^{-1}) and PBN 4751-02 (28.39 qt. ha^{-1}) found *at par* with superior check AKAW 4210-6. However, significantly lowest grain yield was recorded in PBN 4905 and AKAW 4927 (22.48 and 26.66 qt. ha^{-1}, respectively) in heat stress condition. The reduction in general mean grain yield (kg ha^{-1}) to the extent of 0.11 % in second year when compared with first year. Similar result has been showed by Neware et al. [25].

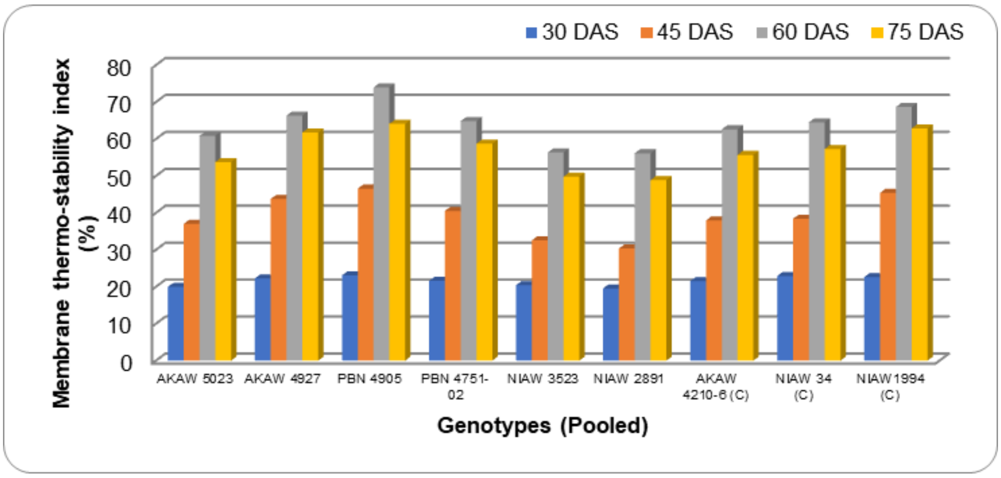

Fig. 3. Membrane thermo-stability index (%)

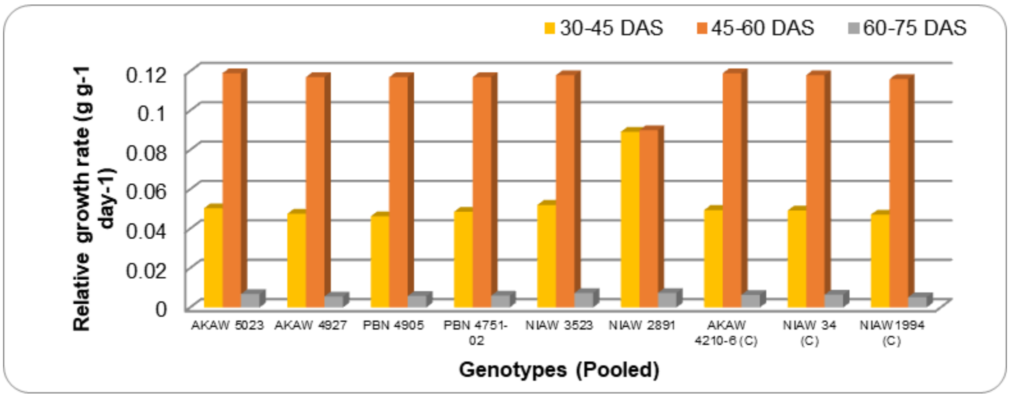

Fig. 4. Relative growth rate (RGR)

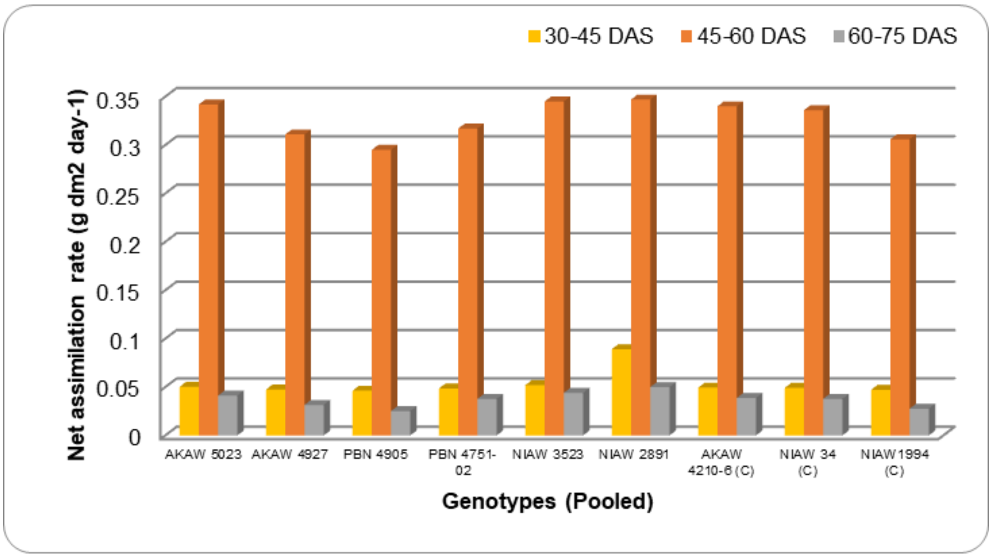

Fig. 5. Net assimilation rate (NAR)

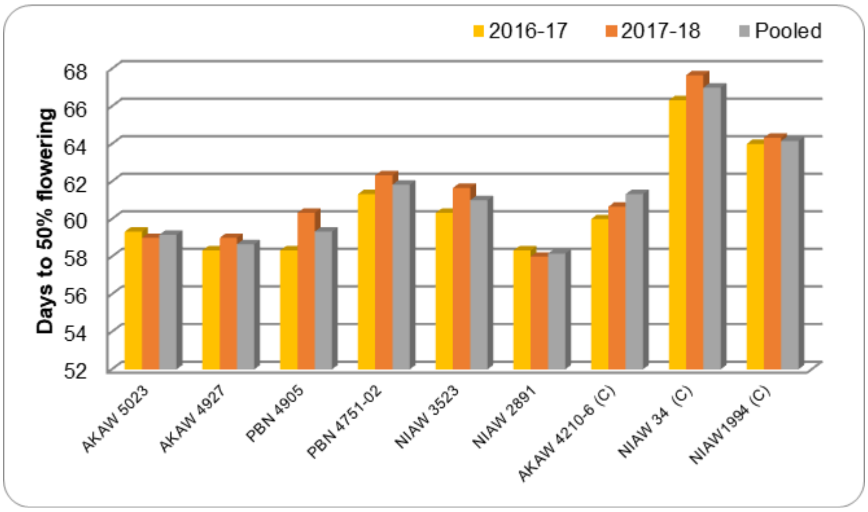

Fig. 6. Days to 50% anthesis

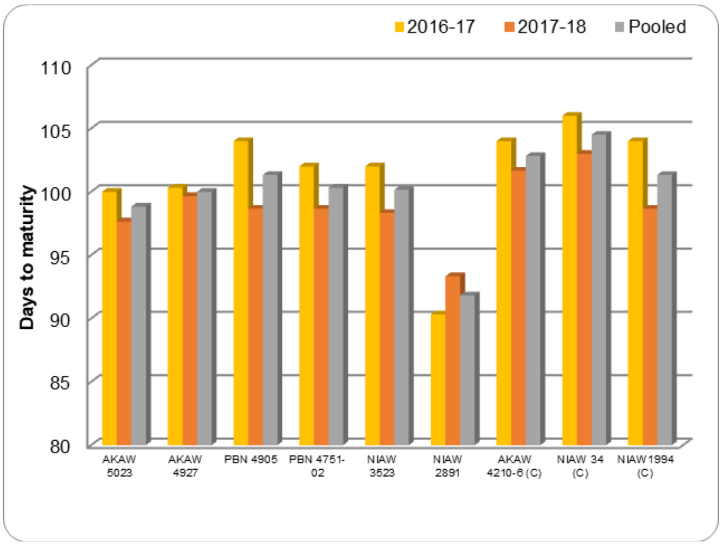

Fig. 7. Days to maturity

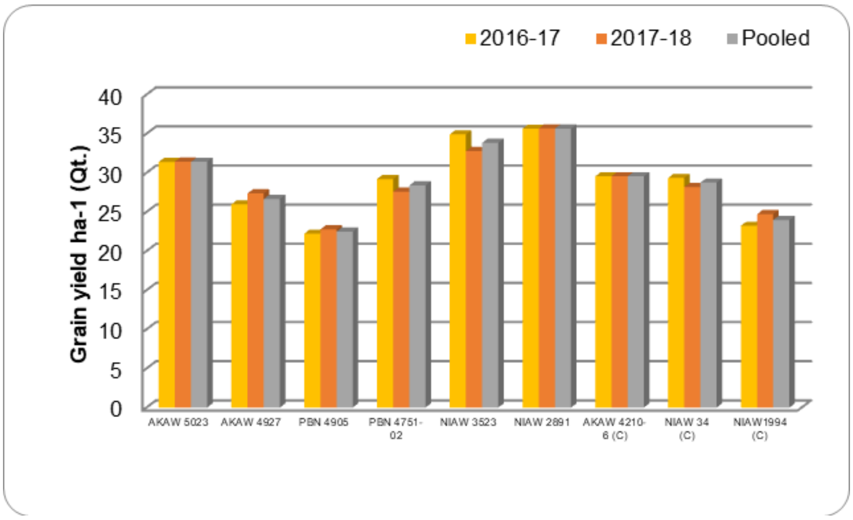

Fig. 8. Grain yield

Table 1. Correlation study of physiological parameters with yield of wheat under heat stress condition

	CT 30 DAS	CT 45 DAS	CT 60 DAS	CT 75 DAS	CTD 30 DAS	CTD 45 DAS	CTD 60 DAS	CTD 75 DAS	MTSI 30 DAS	MTSI 45 DAS	MTSI 60 DAS	MTSI 75 DAS	RGR 30-45 DAS	RGR 45-60 DAS	RGR 60-75 DAS	NAR 30-45 DAS	NAR 45-60 DAS	NAR 60-75 DAS	Yield/ ha
CT 30 DAS	1	0.443	0.276	0.205	-0.262	-0.582	-0.075	-0.392	-0.285	0.473	0.381	0.326	-0.084	0.201	0.062	-0.218	-0.156	-0.201	-0.215
CT 45 DAS		1	0.459	0.417	-0.265	-0.863**	-0.187	-0.594*	-0.336	0.659*	0.467	0.523	-0.363	0.170	-0.350	-0.373	-0.427	-0.401	-0.507
CT 60 DAS			1	0.713**	-0.166	-0.511	-0.757**	-0.760**	-0.069	0.546	0.689**	0.668*	-0.360	0.280	-0.418	-0.327	-0.321	-0.607*	-0.643*
CT 75 DAS				1	-0.142	-0.521	-0.726**	-0.854**	0.131	0.657*	0.638*	0.743**	-0.514	0.407	-0.570*	-0.433	-0.517	-0.759**	-0.735**
CTD 30 DAS					1	0.355	-0.033	0.202	0.375	-0.308	-0.153	-0.014	0.171	0.097	0.027	0.117	0.212	-0.063	0.126
CTD 45 DAS						1	0.208	0.697**	0.444	-0.756**	-0.507	-0.561	0.411	-0.159	0.339	0.411	0.458	0.418	0.526
CTD 60 DAS							1	0.686**	-0.423	-0.394	-0.621*	-0.627*	0.308	-0.345	0.526	0.275	0.468	0.771**	0.677*
CTD 75 DAS								1	0.052	-0.752**	-0.711**	-0.744**	0.580	-0.437	0.609*	0.505	0.537	0.762**	0.766**
MTSI 30 DAS									1	-0.298	0.047	0.013	0.162	0.180	-0.048	0.133	-0.068	-0.267	-0.088
MTSI 45 DAS										1	0.545	0.730**	-0.534	0.269	-0.564	-0.540	-0.654	-0.606*	-0.690**
MTSI 60 DAS											1	0.593*	-0.304	0.330	-0.467	-0.378	-0.463	-0.699**	-0.712**
MTSI 75 DAS												1	-0.459	0.336	-0.612*	-0.512	-0.553	-0.781**	-0.746**
RGR 30-45 DAS													1	-0.590*	0.531	0.859**	0.336	0.497	0.524
RGR 45-60 DAS														1	-0.145	-0.640*	-0.019	-0.398	-0.327
RGR 60-75 DAS															1	0.534	0.633*	0.764**	0.704**
NAR 30-45 DAS																1	0.363	0.546	0.545
NAR 45-60 DAS																	1	0.363	0.640*
NAR 60-75 DAS																		1	0.845**
Yield/ha																			1

Correlation coefficient among different physiological traits under heat stress condition showed that grain yield was significantly and positively correlated with canopy temperature at 75 DAS (r=0.735**), canopy temperature depression at 60 DAS (r=0.677*), canopy temperature depression at 75 DAS (r=0.766**), RGR at 60-75 DAS (r=0.704**), NAR at 45-60 DAS (r=0.640*) and NAR 60-75 DAS (r=0.845**). However, canopy temperature at 60 DAS (-0.643*), membrane thermo-stability index at 45 DAS (-0.690**), membrane thermo-stability index at 60 DAS (-0.712**) and membrane thermo-stability index at 75 DAS (-0.682*) showed negative and significant correlation with grain yield [26,27].

4. CONCLUSION

The increase of crop productivity under heat stress could be achieved by manipulating traits associated with high temperature tolerance. It can be attained through optimum low canopy temperature, high canopy temperature depression, high NAR and RGR etc. and various physiological aspects.

In the present study NIAW 2891, NIAW 3523, AKAW 5023 and AKAW 4210-6 performed well under heat stress in respect of physiological and growth traits. These genotypes maintained cooler canopy, gas exchange and osmotic adjustment under heat stress condition. The present investigation concluded that the physiological indices early flowering and maximum rate of grain filling, minimum days taken to grain filling, early maturity enables plant to escape heat stress. While low canopy temperature and high canopy temperature depression play an important role in improving yield under heat stress condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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