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The Terminal Heat Stress and its Effect on Yield and Yield Contributing Traits of Wheat (*Triticum aestivum L.*) Genotypes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

An experiment was conducted with wheat genotypes NWL-14, K-9162, NWL-1014, NWL-12-2, NWL-12-4, NWL-10-4, K-910-30, NWL-4035, DBW-16, DBW-187, NWL-12 (3) T, Halna, HD-2967 to evaluate heat tolerant in wheat at instructional farm and in the laboratory of Crop Physiology &

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Plant Molecular Biology and Genetic Engineering, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, India, during rabi season of 2021-2022. Heat stress was induced by delayed sowing 45 days from normal date of sowing (02 December 2022)-(17 January 2023) so that delay sown wheat genotypes could experience heat stress at reproductive stage. Heat tolerant wheat genotypes screened on the basis of Relative Water Content, Catalase activity, plant height, tiller number, number of grains per spike, test weight and grain yield per plant over control under heat stress condition. Heat stress reduces the the growth and yield irrespective of wheat genotypes but heat tolerant genotypes Halna, NWL-1293)T, NWL 10-2 and NWL-12-4 showed less reduction over susceptible ones. Relative water content, proline and catalase activity can be used as a physiological screening indices for heat tolerant genotypes.

Keywords: Heat; relative water content; proline content; catalase activity; yield; yield components.

1. INTRODUCTION

"Wheat (*Triticum spp*.) is one of the major cereal crops belonging to Poaceae family which contributes about 30% of world grain production and 50% of the world grain trade. Wheat is considered as staple food in more than 40 countries of the world which provides basic calories and protein for 85% and 82% of the world population respectively. Food and Agriculture Organization (FAO) estimated that, the annual cereal production has to grow by almost one billion to feed the projected population of 9.1 billion by 2050. In order to meet the increase food requirement, increase in crop production and productivity is the demand of 21st century" [1]. "In India, the area of wheat 2020-21 in 31.61 million hectares with a production of 109.52 million tons and productivity was 3464 kg/ha. In Uttar Pradesh the area of wheat crop 9.85 million hectare with a production of 35.50 million tons and productivity 3604 kg/ha" [2].

It is eaten in various forms by more than 1000 million human beings in the world. In India it is 2nd important staple food crop rice being the first. It is eaten in the form of chapattis, puris, Dalia, halwa etc. They are principally concerned in providing the gluten substance which is very essential for bakery products. In bakery gluten provides the structural frame works for the familiar spongy, cellular texture of bread and other baked products. Besides staple food for human beings, wheat straw is a good source of feed for a large population of cattle in our country. It contains more protein than other cereals. Wheat has a relatively high content of niacin and thiamine.

"The optimum temperature for wheat during the post anthesis period is 22–25 ºC, beyond that wheat feels the heat, leading to irreversible damage by high temperature" [3]. It has been reported that each degree rise above cardinal temperature causes 4% reduction in grain number [4], grain weight 5% [5] and grain yield 53.05% [6]. "High temperature stress is a major environmental factor that limits yield in wheat and affects wheat yield either through chronic stress by prolonged, moderate temperatures up to 32°C or through heat-shock, which is sudden, but comparatively brief exposure to 33°C and above" [7]. "The impact of high temperature stress on crop depends up on intensity, rate of increase, duration of stress and stage of crop development" [8,9]. "High temperature stress induces several alterations in physiological, biochemical and molecular components of wheat crop production" [10].

"The heat stress occurs usually for rising of canopy temperature that depends on air and soil temperature, soil and canopy properties, and loss of soil moisture. High temperature affects crops in different ways including poor germination and plant establishment, reduced photosynthesis, leaf senescence, decreased pollen viability, and consequently production of less grains with smaller grain size" [11-14].

2. MATERIALS AND METHODS

The experiment was conducted in field and lab with thirteenth wheat genotypes namely NWL-14, K-9162, NWL-1014, NWL-12-2, NWL-12-4, NWL-10-4, K-910-30, NWL-4035, DBW-16, DBW-187, NWL-12 (3) T, Halna, HD-2967 at Student Instructional and in the Laboratory of Department of Plant Molecular Biology and Genetic Engineering, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) during the Rabi season of 2021-22 to evaluate terminal heat stress in wheat genotypes.

Geographically, Ayodhya comes under sub-tropical climatic zone of Indo-Gangatic alluvium of eastern Uttar Pradesh, India. It is situated at about 24.40 to 26.560 N latitude and 82.120 to 83.980 east longitude at an altitude of 113 meter above mean sea level (MSL). The average annual rainfall of this region is about 1280 mm. Generally, April and May are the hottest months of the year. The soil of the experimental site was clay loam in reaction, rich in phosphorus, potassium and having lower organic carbon content with poor nitrogen availability. The experiment was conducted in a randomized block design with three replications. Mainly two treatments are given late sowing treatment and very late. Normal sowing are considered in 2 December 2022 and delayed sowing in 17 January 2023.The unit plot size was 2 × 2m^2. The spacing between row to row and plant to plant were 22cm and 5cm, respectively. Fertilizers including N, P, K, were applied at the rate of 120:60:40 kg ha−1, respectively, in the form of urea (N: 46%), triple supper phosphate (TSP: 50% P_2O_5), murate of potash (MP: 60% K_2O), respectively. Full doses of all fertilizers except N (one-third) were incorporated thoroughly into the soil as basal dose. The remaining N was further split into two doses for application at 20 and 50 days after sowing (DAS). Wheat seeds of all genotypes were sown using hand hoe and shallow irrigation was applied in all plots after 20-25 days after sowing at the time of crown root initiation. Plots were irrigated three times (at 20-25, 50-55, and 70-75 DAS, and using some pots for sowing wheat crop in the net house were not irrigated throughout the growing period and protected from rainfall to maintain DS condition. The crop was kept weed-free, and to control diseases for weed control using 2-3 hand weeding. Relative water content [15], Proline content [16], Catalase activity [17], plant height, tiller number, number of grains per spike, test weight and grain yield per plant as per standard methodology.

3. RESULTS AND DISCUSSION

Relative water content abruptly decreased in all wheat genotypes after heat stress (Fig.1). High relative content was estimated in NWL-12-3(T) (86.73%) followed by HD-2967 (86.30%), NW-4035 (86.04%) under control condition and NW-10-14 (73.99%) and K-910-30 (72.53%) under stress condition. Maximum percent reduction in DBW-187 (30.51%) while minimum in HD-2967 (13.82%). Heat stress damaged plants root conductance despite enough supply of water, while this becomes more fatal for plant when heat stress along with drought was applied due to more water transpiration demands [18-21].

Proline content was increased in wheat genotypes after heat stress (Fig. 2). High Proline content was recorded in HD-2967 (23.08%) followed by K-910-30 (22.51%) and NWL-12-3(T) (21.65%) under control condition. In stress condition high proline content was estimated in NWL-12-3 (T) (80.14%) and K-910-30(79.58%). Maximum percent increased in K-9162 (363.73%), DBW- 16 (357.57%) while minimum in HD-2967 (70.85%). “Similar results of higher proline and total soluble sugar accumulation in plants under stress environments as compared to normal condition” [22]. “Proline and sugars are among the well-known organic osmolyte and accumulation of proline under stress conditions have been observed in many plants' species” [23-25].

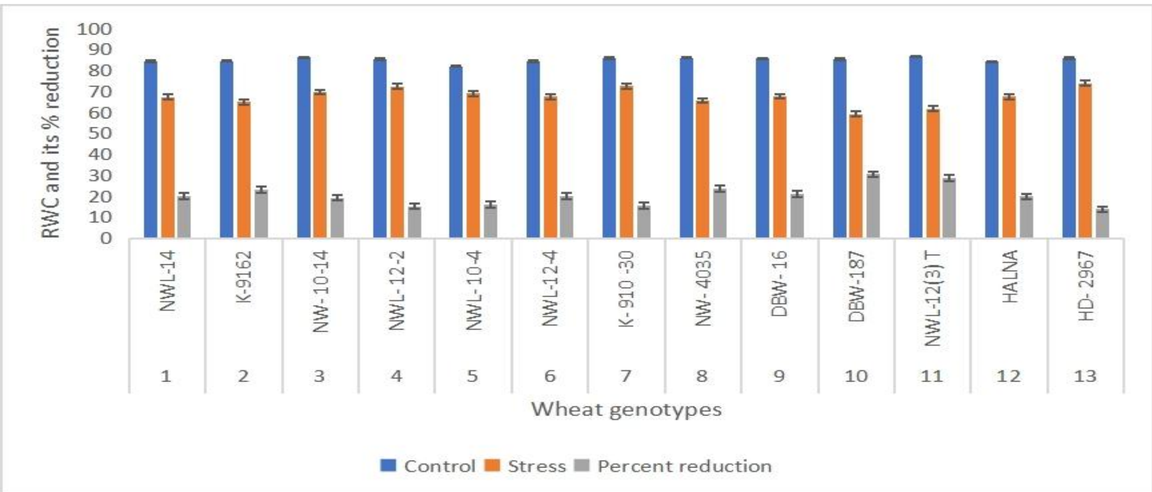

Fig. 1. Effect of heat stress on relative water content (%) of wheat genotypes

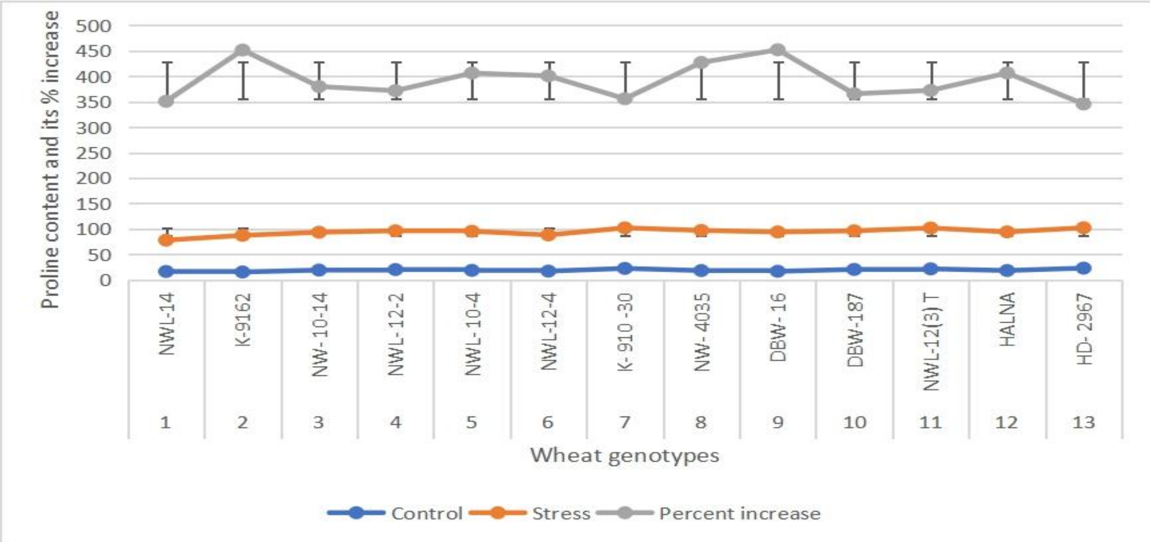

Fig. 2. Effect of heat stress on proline content (%) of wheat genotypes

The Catalase activity abruptly increased in all wheat genotypes (Fig.3). The maximum catalase activity was recorded in NWL-12-3(T) (70.70g), NWL-10-4 (67.52g) and NW-4035 (67.02g), while lowest in DBW-16 (63.43g) under control condition. The maximum catalase activity was observed under heat stress condition in NWL-12-2 (135.58g) and K910-30 (135.16g) while minimum in HD-2967 (131.07). The maximum percent increase was recorded in DBW-16 (109.57%) and minimum in NWL-12-3 (T) (89.80%). "The catalase activity in different lines under drought stress remained unchanged or decreased, as against control conditions"[26,27]. "But among the different lines (drought tolerant and sensitive) no particular pattern of activity of this enzyme was observed" [28,29].

Wheat genotypes showed genetic variability in plant height (Fig. 4). The maximum plant height was recorded in NWL-14 (129.6cm) and minimum in HALNA (74.4cm) under control condition. The Stability in plant was highly fluctuated under heat stress in wheat genotypes due to their generic level of heat tolerance. The maximum reduction was recorded in NWL-14 (43.36%) followed by HD-2967 (28.86%) and K-9162 (21.33%) while minimum in NW-4035 (1.92%) followed by HALNA (10.48%), NW-10-14 (14.50%), NWL-10-4 (15.85%), DBW-187 (18.25%). in terms of percent reduction over control. A reduced plant height during heat stress seems to be related with impaired meristematic cell division and cell elongation [30-32].

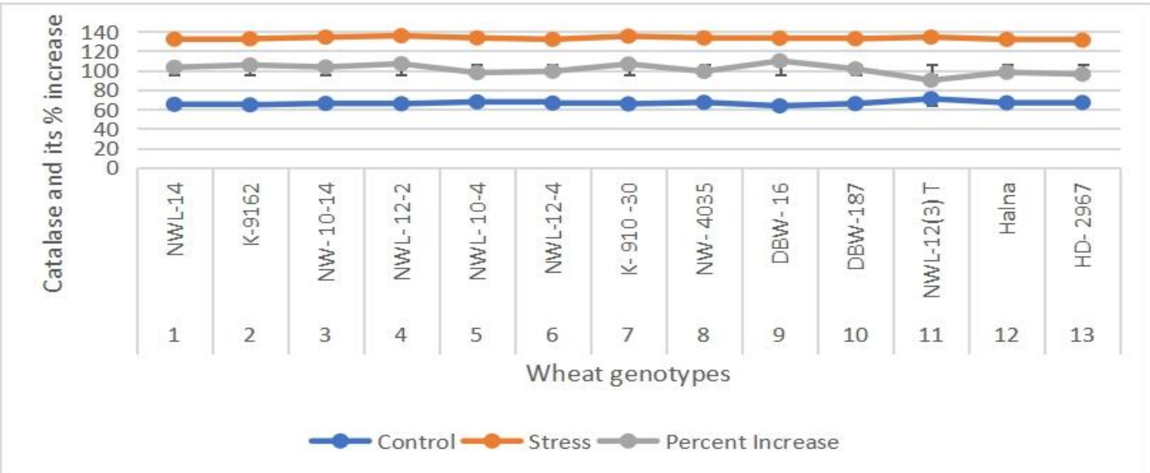

Fig. 3. Effect of heat stress on catalase activity (ugg-1fw basis unit^{-1*}) of wheat genotypes

**1 unit (U) is the amount of enzyme that catalyses the reaction of 1 nmol of substrate per minute*

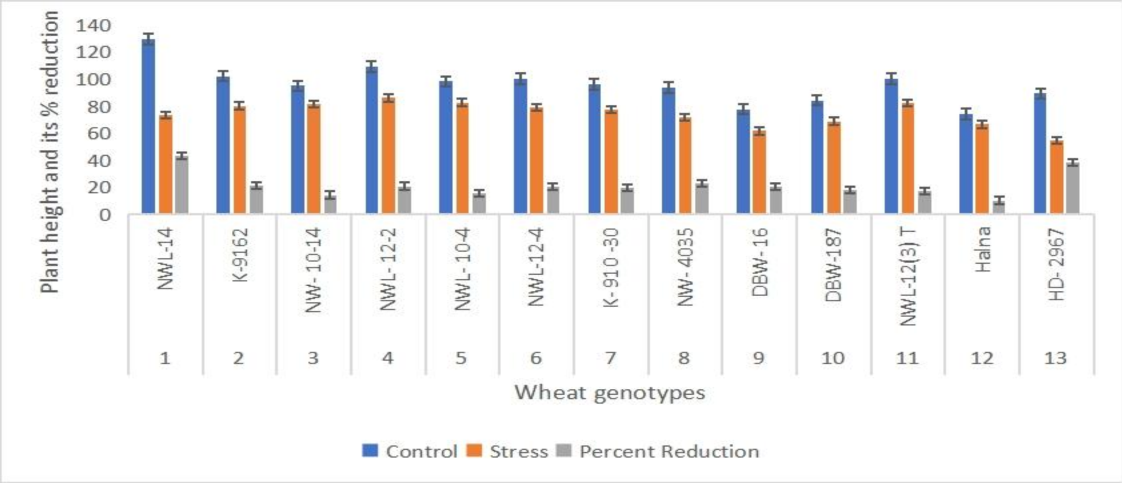

Fig. 4. Plant height (cm) and its percent reduction over control of wheat genotypes under heat stress condition

Tiller number per plant: Wheat genotypes showed significant variability in number of tillers per plant (Fig. 5). Under control condition the maximum tiller number was recorded in NWL-12-4 (5.9), and minimum in DBW 16 (3.8). The heat stress had significant effect on tiller number per plant and reduced it in all wheat genotypes. The maximum per cent reduction in tiller numbers was recorded in NWL-14 (34.78%) and minimum in NWL-10-4 (5.56%). NWL-12-4 (8.47%), NWL-1014- (12.50%). Heat stress reduced plant height by disturbing the physiological developmental process and followed forced maturity. Similar type finding was also reported by Duggan and Prasad et al. [33,34].

Number of grains spike^{-1}: Wheat genotypes showed genetic variability in number of grains spike-^{1} under control andheat stress condition (Fig. 6). High number of grains in main spike was noted in NWL-12-4 (76.5), NW-4035 (67.6), K-9162 and DBW-16 (62.2) while less number of grains recorded in HALNA (51.25), K-910-30 (53.0), NW-10-14 (53.8) and NWL-12-3(T) (55.2). Under heat stress condition the maximum number of grains recorded in K-9162 (41.8), K-910-30 (40.4) and NW-4035 (39.2). Heat stress reduction the grains in main spike irrespective of wheat genotypes. High reduction in number of grains in main spike was obtained in NWL-12-4 (53.0%), DBW-187 (44.63 %) and NWL-10-4 (42.14 %) while less in K-910-30 (23.77 %), NW-10-14 (31.97 %) and K-9162 (32.80%) under heat stress regions. Grain reduction is caused by programmed cell death at high temperatures produced by ethylene levels [35]. When meiosis and abiotic stress occurs at the same time, the initial step of gamete formation may be harmed even more [36].

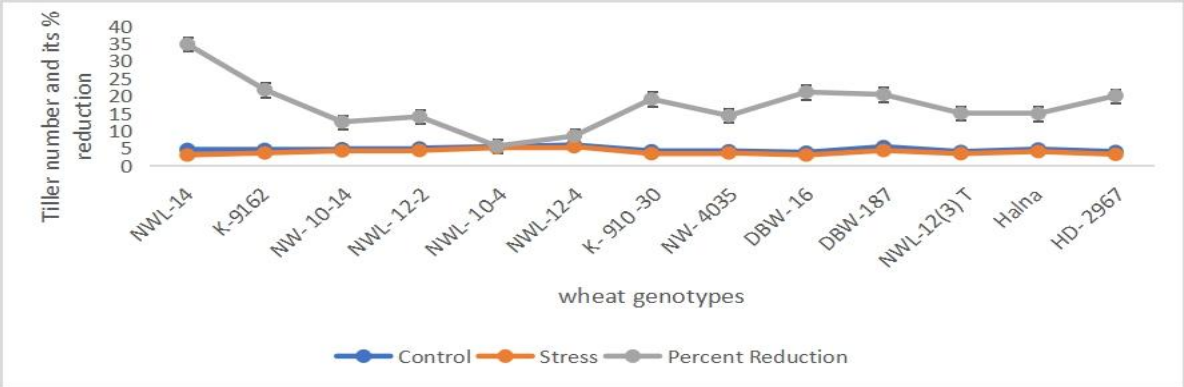

Fig. 5. Effect of heat stress on tiller number of wheat genotypes

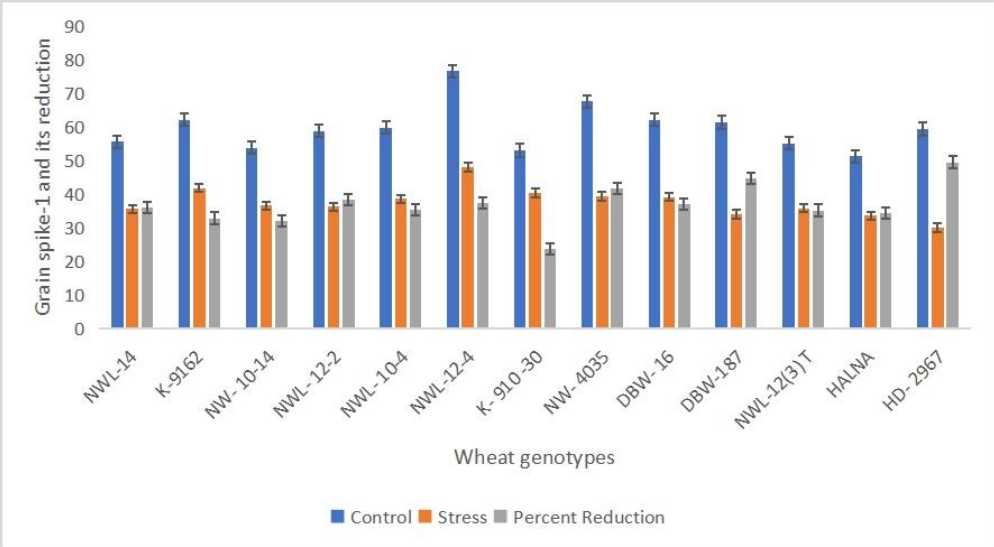

Fig. 6. Effect of heat stress on Number of grains spike^{-1} (g) of wheat genotypes

Test weight: The wheat grains showed significant variation in test weight under control and heat stress condition (Fig.7). The genotypes that showed maximum test weight under control condition were DBW-187 (43.68 g), NW-4035 (41.08 g), DBW-16 (40g) and HALNA (38.0 g) while minimum in NWL-14 (30.0g). The maximum test weight under stress condition were K-910-30 (29.96g) and minimum in NWL-10-14 (19.0g). The maximum percent reduction recorded under heat stress condition NW-4035 (49.85g), DBW-187 (45.05g) and NWL-12-2 (40.94g). Heat stress significantly reduced grains number per spike and 1000 grain weight, shape and size wheat grains [37]. The increasing temperature (from 25-35^{o}C) during grain growth decrease grain size and promotes grain shrinking and reduced the individual grain weight [38].

Heat stress had significant effect on grain yield/ plant in control condition (Fig. 8). The maximum grain yield per plant was recorded in Halna (12.23g), NWL12-4 (10.57 g) and NWL-10-4 (10.27 g) while minimum DBW-187 (6.96 g), HD-2967 (7.33 g), and NW-10-14 (7.65) under heat control condition. Under heat stress condition maximum grain yield recorded in HALNA (7.71g) and NWL-12-4 (5.21g) while minimum in NWL-10-4 (3.11g) and DBW-187 (33.20g) markedly reduced grain yield in all wheat genotypes. The maximum reduction in grain yield was noted in NWL-10-4 (69.72%) and

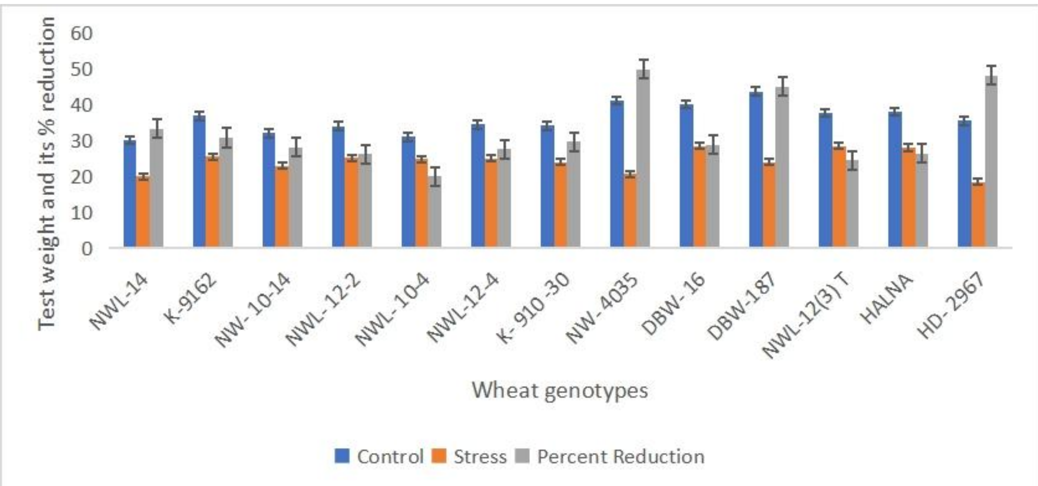

Fig. 7. Test weight (g) and its percent reduction of wheat genotypes under heat stress condition over control

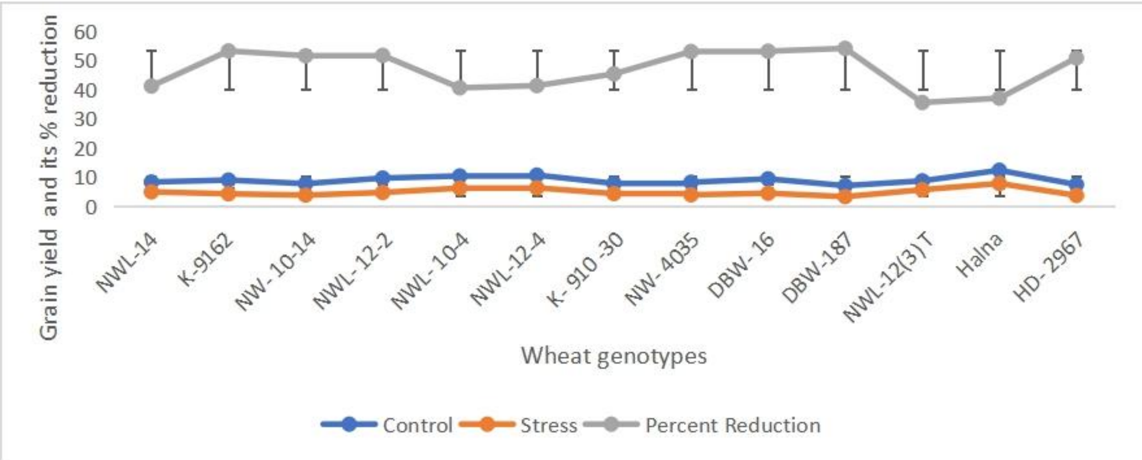

Fig. 8. Effect of heat stress on yield per plant (g) of wheat genotypes

K-910-30 (58.19%) followed by DBW-187 (54.08 %) and minimum reduction was recorded in HALNA (37 %) and NWL-14 (41.03%). "Heat stress decreases the yield due to affecting growth and development processes, lowering the yield component potential and affecting the activity of key enzymes that contribute a lot during grain filling and development" [39-43].

4. CONCLUSION

The heat tolerant genotypes Halna, NWL -1293)T, NWL 10-2. NWL -12-4 had high relative water content, proline content, Catalase activity and less reduction in yield and yield components under heat stress regimes. High relative water content, proline content and catalase activity maintain the physiological function of upto some extent under heat stress regime and stability in yield. These physio-biochemical indices can be used for screening for heat tolerant in wheat.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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