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RESPONSES OF DIFFERENTIAL PHYSIO-BIOCHEMICAL TRAITS OF BREAD WHEAT MUTANTS DURING TERMINAL HEAT STRESS

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ABSTRACT

Wheat (*Triticum aestivum* L.) also known as Bread wheat is an important foodstuffs crop belonging to grass family Poaceae (Graminiae) with chromosome number 2n=6x=42. The productivity of Wheat is challenged by abiotic stresses like terminal heat stress. Terminal heat stress has become one of the major threats due to global climate change which is significantly affecting the physiological, biochemical parameters as well as production and productivity of Wheat crop. The present study included 34 mutant genotypes of the Borlaug 100 variety of Wheat along with two checks, viz., HD 2967 (heat tolerant) and GW 322 (heat susceptible), in two different environments i.e., optimum environments and heat stress environments for biochemical parameters such as, total protein, total soluble sugar and physiological parameters like, total chlorophyll and total carotenoid correlated with grain yield per plot of the Wheat crop. The research was conducted with an objective of assessment of the responses of differential Physio-biochemical traits of Bread Wheat mutants during terminal heat stress. The investigation revealed that the collaborative physiological and biochemical changes recorded in the 36 wheat mutants during heat stress showed that there was an increase in total chlorophyll, total protein, and total soluble sugars, along with a reduction in carotenoid content reflecting a complex but coordinated adjustable response to Heat stress environments. Conclusively five genotypes namely., TGW-60, TGW-62, TGW-64, TGW-68 and TGW-74 gave superior biochemical and physiological performance so, they can be utilized further for development of Breeding lines for climate resilient cultivar production.

***Keywords*:** Wheat, stress, mutant, physiological, biochemical.

Introduction

Wheat (*Triticum aestivum* L.) commonly known as Bread Wheat belongs to the grass family Poaceae (Graminiae) with chromosome number 2n=6x=42 is an essential foodstuffs crop that is crucial to global food security because it gives a massive percentage of the world's inhabitants vital calories, proteins, and nutrients. However, wheat productivity is more and more challenged by terminal heat stress, specifically during the grain filling stage, which critically impacts photosynthesis, membrane stability, enzyme activity, and eventually grain yield (Zheng *et al.*, 2025). Terminal heat stress refers to elevated temperatures occurring during the reproductive and grain-filling phases of crop development. It is anticipated that a 1°C increase in mean temperature can lead to a 6% drop in world wheat yield (Zhao *et al.*, 2017). With uprising global temperatures because of climate change, the frequency and potency of heat stress events are predicted to increase, making it crucial to understand the crop’s physiological and biochemical reaction to such conditions (IPCC, 2023). These conditions cause premature leaf senescence, reduced grain filling duration, and ultimately a decline in grain yield and quality (Lobell *et al.*, 2012).

Heat stress activates various physiological and biochemical interchanges in wheat crops. Among which, total chlorophyll content is key evidence of photosynthetic efficiency. A reduction in chlorophyll under heat stress meditate damage to the photosynthetic structure, limiting carbon absorption and yield potential. Total carotenoids, on the other hand, are included in photoprotection and oxidative stress moderation. The relative stability or amplification of carotenoid levels under heat stress is often regarded a protective mechanism (Khan *et al*., 2022).

Biochemically, heat stress involves the assemblage of total soluble sugars and total proteins, serve as osmo-protectants and molecular chaperones, respectively. Enhancement in sugar levels helps to sustain osmotic balance and function as respiratory substrates, while proteins, mostly heat shock proteins facilitate protein folding and cellular protection (Zheng *et al*., 2025). These biochemical markers are often frequently linked with the plant's capability to maintain physiological integrity under stress.

In spite of these adaptive responses, grain yield per plot persists the most analytical phenological trait, integrating the effects of stress-induced changes. High-yielding genotypes under heat stress typically showed upgraded maintenance of chlorophyll, carotenoids, protein, and sugar levels, showing their enhanced tolerance. Therefore, assessing the physio-biochemical traits in wheat mutants under terminal heat stress is crucial for recognizing tolerant genotypes and guiding breeding programs toward the evolution of climate-resilient cultivars.

Materials and Methods

The present investigation was carried out at the Experimental Research farm, Department of Genetics and Plant Breeding, College of Agriculture, RVSKVV, Gwalior (M.P) (26.22˚N Latitude and 78.18˚E longitudes) and the physiological and biochemical research work was conducted at Biotechnology Research centre, Department of Biotechnology, RVSKVV, College of agriculture, Gwalior (M.P) during the *Rabi* season 2023-24. The present investigation was undertaken with the objective to evaluate the responses of differential physio-biochemical traits of Bread Wheat mutants during terminal heat stress

Plant material

Thirty-four advanced generation Bread Wheat mutant genotypes named as Trombay Gwalior Wheat (TGW) followed by numeric code i.e., (TGW 1, TGW 8, TGW 10, TGW 16, TGW 20, TGW 25, TGW 27, TGW 48, TGW 55, TGW 60, TGW 62, TGW 64, TGW 68, TGW 69, TGW 72, TGW 74, TGW 78, TGW 84, TGW 85, TGW 88, TGW 90, TGW 91, TGW 92, TGW 93, TGW 101, TGW 102, TGW 103, TGW 105, TGW 109, TGW 110, TGW 114, TGW 120, TGW 125, TGW 134) along with two check varieties, HD-2967 (BARC, Trombay, Mumbai) heat tolerant check and GW-322 (RVSKVV, Gwalior, M.P.) heat susceptible check were undertaken for assessment of different physiological parameters namely; total chlorophyll and carotenoid along with biochemical parameters like, total protein, and total soluble sugar. The mutants were developed by subjecting them to gamma ray irradiation at 300 Gy with 58.6 Gy/min. of dose rate at Nuclear Agriculture & Biotechnology Division, Bhabha Atomic Research Centre, Trombay, Mumbai (NABTD, BARC, Mumbai, India).

Field growing conditions

The weather in Gwalior is specified by high temperatures, dry spells, and uncertain precipitation, with an average annual rainfall of 700 mm. The metrological conditions in this region make it a perfect location for conducting terminal heat stress screening for cool-season crops, such as wheat. The data on weather parameters was obtained from the Meteorological Observatory Unit (MOU) at the College of agriculture, RVSKVV, Gwalior (M.P). The annual rainfall (mm), maximum, minimum temperature, relative humidity and evaporation during the entire crop growth period are presented in Figure 1.

The experimental material was planted in a three-row plot measuring 3 m in length, with three replications following a randomized complete block design. The distance between plants and rows was maintained at 10 cm and 30 cm. Experiments were conducted in two different environments, as described below:

I. Optimum environment (EI): The crop was sown in the last week of November.

II. Heat stress environment (EII): The crop was sown in the last week of December.

The experiment with optimum environment was conducted was watered five times to keep away from the effect of drought on the trial. While the experiment where heat stress environment was conducted was watered every 8-10 days to keep away from the confounding effects of heat and drought stress. The suggested practice packages for this region in terms of fertilization, weeding, and crop protection were adopted to grow healthy wheat crops.

Data collection

A total of two biochemical and two physiological parameters were recorded in each 36 Wheat mutants, as mentioned below.

Morphological parameters

Data on grain yield per plot was recorded in two environments i.e., optimum environment and heat stress environment. Comparative study of yield with respect to biochemical and physiological parameter was done for both the environments.

Biochemical parameters

Leaf samples were collected at 35 DAA (days after anthesis) and subjected to biochemical studies in both the environments.

Extraction and estimation of Biochemical contents

Extraction Procedure:

250 mg of flag leaf tissue of Wheat mutants was homogenized in 5 ml of 80% methanol and then incubated at 80°C for 1 hour. The extract was centrifuged twice at 10,000 rpm for 10 min. Than the supernatant was vacuum-dried and rehabilitate in 1 ml distilled water for further analysis.

Total Soluble Sugar was evaluated on the basis of Anthrone reagent method suggested by Dubois *et al.* (1956). Total protein was evaluated using standard protocol of Lowry *et al.* (1951) utilizing the bovine serum albumin (BSA) as the standard.

Estimation of Physiological parameter

Total chlorophyll was calculated as per method given by Arnon *et al.* (1949). It was estimated on 75 days after sowing. Carotenoid content was measured by taking the reading of spectrophotometer at 470 nm.

Statistical analysis

The combined statistical analysis of all morphological, biochemical and physiological traits was computed using the Windostat 9.30 software and R 4.4.3 software.

Results and Discussion

Total chlorophyll content increased from 2.23 mg/g to 2.30 mg/g for TGW-1, 2.24 mg/g to 2.26 mg/g for TGW-8, 2.24 mg/g to 2.31 mg/g for TGW-10, 2.29 mg/g to 2.31 mg/g for TGW-20, 2.26 mg/g to 2.33 mg/g for TGW 25, 2.46 mg/g to 2.48 mg/g for TGW-27, 2.23 mg/g to 2.25 mg/g for TGW-48, 2.12 mg/g to 2.27 mg/g for TGW-69, 2.13 mg/g to 2.25 mg/g for TGW-72, 1.97 mg/g to 2.25 mg/g for TGW-74, 2.08 mg/g to 2.26 mg/g for TGW-78, 2.11 mg/g to 2.18 mg/g for TGW-84, 2.12 mg/g to 2.22 mg/g for TGW-85, 1.96 mg/g to 2.24 mg/g for TGW-88, 2.14 mg/g to 2.18 mg/g for TGW-90, 2.14 mg/g to 2.20 mg/g for TGW-92, 2.16 mg/g to 2.19 mg/g for TGW-93, 1.88 mg/g to 2.23 mg/g for TGW-101, 2.11 mg/g to 2.26 for TGW-105, 2.21 mg/g to 2.22 mg/g for TGW-109, 2.22 mg/g to 2.24 mg/g for TGW-125, 2.47 mg/g to 2.48 mg/g for TGW-134, 2.21 mg/g to 2.25 mg/g for HD 2967 (C), 2.22 mg/g to 2.25 mg/g for GW 322 (C). The results have been discussed in table 1 and table 2 respectively. Among all these mutant genotypes three genotypes namely, TGW-74, TGW-88 and TGW-101 showed maximum increase in their Chlorophyll content during heat stress environment. In the current study, a substantial increase in total chlorophyll content was reported in several wheat genotypes under terminal heat stress in comparison to the optimum environment. Similar results have been reported by Kumar *et al.*, 2013 and Sharma *et al.*, 2015. They suggested that this response, suggests a feasible adaptive physiological adaptation by the genotypes to balance photosynthetic efficiency during stress conditions. While Chatterjee *et al.*, 2023 reported the same results suggesting that the enhancement in chlorophyll content might be credited to the stimulation of stress-protective routes, involving the overexpression of antioxidant systems and heat shock proteins that safeguard chloroplast structures.

Carotenoid content decreased from optimum environment to heat stress environment like., TGW-1 decreased from 3.85 mg/g to 2.84 mg/g, TGW-8 decreased from 3.79 mg/g to 2.87 mg/g, TGW-10 decreased from 3.86 mg/g to 2.86 mg/g, TGW-20 decreased from 3.84 mg/g to 3.12 mg/g, TGW-25 decreased from 3.86 mg/g to 2.82 mg/g, TGW-27 decreased from 3.97 mg/g to 3.70 mg/g, TGW-48 decreased from 3.81 mg/g to 2.97 mg/g, TGW-55 decreased from 3.86 mg/g to 2.81 mg/g, TGW-60 decreased from 3.81 mg/g to 2.97 mg/g, TGW-62 decreased from 3.84 mg/g to 2.33 mg/g, TGW-64 decreased from 3.8 mg/g to 2.35 mg/g, TGW-68 decreased from 3.83 mg/g to 2.35 mg/g, TGW-69 decreased from 3.82 mg/g to 2.9 mg/g, TGW-72 decreased from 3.84 mg/g to 2.98 mg/g, TGW-78 decreased from 3.48 mg/g to 2.94 mg/g, TGW-84 decreased from 3.8 mg/g to 2.92 mg/g, TGW-85 decreased from 3.48 mg/g to 2.91 mg/g, TGW-88 decreased from 2.74 mg/g to 2.92 mg/g, TGW-90 decreased from 3.81 mg/g to 2.91 mg/g, TGW-91 decreased from 3.97 mg/g to 3.79 mg/g, TGW-92 decreased from 3.79 mg/g to 2.86 mg/g, TGW-93 decreased from 3.48 mg/g to 2.92 mg/g, TGW-101 decreased from 3.49 mg/g to 2.92 mg/g, TGW-102 decreased from 3.98 mg/g to 3.9 mg/g, TGW-105 decreased from 3.46 mg/g to 3.01 mg/g, TGW-109 decreased from 3.5 mg/g to 3.05 mg/g, TGW-110 decreased from 3.47 mg/g to 3.05 mg/g, TGW-114 decreased from 3.49 mg/g to 3.08 mg/g, TGW-120 decreased from 3.46 mg/g to 3.08 mg/g, TGW-125 decreased from 3.83 mg/g to 3.08 mg/g, TGW-16 decreased from 3.95 mg/g to 3.9 mg/g, HD 2967 (C) decreased from 3.8 mg/g to 3.06 mg/g and GW 322 (C) decreased from 3.81 mg/g to 3.06 mg/g. Overall, three genotype namely, TGW-74, TGW-103 and TGW-134 showed increase of carotenoid content from optimum environment to heat stress environment.

In the current study, carotenoid content showed a noticeable reduction in most of wheat mutant genotypes during heat stress in comparison to the optimum environment. This reduction may be credited to the temperature sensitivity of carotenoids, which are vulnerable to disintegration under raised temperatures because of oxidative stress. Similar results have been reported by Alghabari *et al.* (2021) and Sangwan *et al.* (2018). They suggested that during heat stress, the frequency of ROS production often exceeds the plant's detoxification function, which leads to oxidative breakdown of carotenoids. Furthermore, Tabassum *et al.* (2023) reported the same result suggesting that high temperatures can diminish the activity of enzymes associated with carotenoid biosynthesis, like phytoene synthase, leading to decreased pigment synthesis.

Total protein content increased from optimum environment to heat stress environment such as., TGW-10 increased from 2.93 mg/g FW to 3.19 mg/g FW, TGW-48 increased from 3.01 mg/g FW to 4 mg/g FW, TGW-55 increased from 2.28 mg/g FW to 3.07 mg/g FW, TGW-60 increased from 2.18 mg/g FW to 5.14 mg/g FW, TGW-62 increased from 3.26 mg/g FW to 5.17 mg/g FW, TGW-64 increased from 3.51 mg/g FW to 5.13 mg/g FW, TGW-68 increased from 3.6 mg/g FW to 5.11 mg/g FW, TGW-69 increased from 3.06 mg/g FW to 3.07 mg/g FW, TGW-72 increased from 2.77 mg/g FW to 3.23 mg/g FW, TGW-85 increased from 2.91 mg/g FW to 3.28 mg/g FW, TGW-88 increased from 4 mg/g FW to 5.12 mg/g FW, TGW-90 increased from 3.2 mg/g FW to 3.23 mg/g FW, TGW-91 increased from 2.31 mg/g FW to 2.56 mg/g FW, TGW-102 increased from 2.24 mg/g FW to 2.56 mg/g FW, TGW-110 increased from 3.15 mg/g FW to 3.25 mg/g FW, TGW-114 increased from 2.29 mg/g FW to 3.13 mg/g FW, TGW-125 increased from 3.12 mg/g FW to 3.29 mg/g FW, TGW-134 increased from 2.42 mg/g FW to 2.56 mg/g FW, TGW-16 increased from 2.3 mg/g FW to 2.53 mg/g FW, HD 2967 (C) increased from 2.35 mg/g FW to 2.53 mg/g FW, GW 322 (C) increased from 2.27 mg/g FW to 2.54 mg/g FW. Overall, four genotype namely, TGW-60, TGW-62, TGW-64 and TGW-68 showed maximum increase of protein content from optimum environment to heat stress environment.

So, a significant increase in total protein content was observed in most of the wheat mutant genotypes under heat stress conditions compared to the optimum environment. This increase in protein assemblage during stress condition may be credited to the induction of stress-responsive proteins, which include heat shock proteins (HSPs) and some other protective and regulatory proteins that assist to mitigate the damaging effects of high temperatures. Similar results have been reported by Kakanur *et al.* (2024), Kumar *et al.* (2023), Mahdavi *et al.* (2022). They suggested that during heat stress, plants switch on a broad range of heat-responsive genes that result in the synthesis of new proteins precisely involved in cellular protection, repair, and stabilization of protein structures.

Among these, HSPs serve as molecular chaperones, preventing the accumulation of denatured proteins, assisting in protein refolding, and stabilizing cellular membranes and enzymes (Mustafa *et al.*, 2021, Kotak *et al.*, 2007). The incremental effect of these stress-induced proteins results an overall enhancement in measurable total protein content.

Total soluble sugar increased from optimum environment to heat stress environment such as., TGW-1 increased from 5.09 mg/g FW to 6.19 mg/g FW, TGW-8 increased from 4.29 mg/g FW to 6.24 mg/g FW, TGW-10 increased from 4.04 mg/g FW to 5.98 mg/g FW, TGW-20 increased from 5.1 mg/g FW to 5.64 mg/g FW, TGW-25 increased from 4.12 mg/g FW to 5.66 mg/g FW, TGW-27 increased from 3.76 mg/g FW to 4.55 mg/g FW, TGW-48 increased from 4.37 mg/g FW to 5.48 mg/g FW, TGW-55 increased from 3.3 mg/g FW to 5.48 mg/g FW, TGW-60 increased from 3.27 mg/g FW to 8.87 mg/g FW, TGW-62 increased from 4.31 mg/g FW to 8.84 mg/g FW, TGW-64 increased from 4.02 mg/g FW to 8.85 mg/g FW, TGW-68 increased from 4.54 mg/g FW to 8.85 mg/g FW, TGW-69 increased from 4.11 mg/g FW to 5.43 mg/g FW, TGW-72 increased from 4.59 mg/g FW to 5.59 mg/g FW, TGW-78 increased from 5.19 mg/g FW to 5.35 mg/g FW, TGW-84 increased from 5 mg/g FW to 5.23 mg/g FW, TGW-85 increased from 4.12 mg/g FW to 5.49 mg/g FW, TGW-88 increased from 5.22 mg/g FW to 8.83 mg/g FW, TGW-90 increased from 4.8 mg/g FW to 6.19 mg/g FW, TGW-91 increased from 3.72 mg/g FW to 4.55 mg/g FW, TGW-101 increased from 5.14 mg/g FW to 5.47 mg/g FW, TGW-102 increased from 3.72 mg/g FW to 4.54 mg/g FW, TGW-110 increased from 4.21 mg/g FW to 5.5 mg/g FW, TGW-114 increased from 3.44 mg/g FW to

5.91 mg/g FW, TGW-120 increased from 4.44 mg/g FW to 5.19 mg/g FW, TGW-125 increased from 4.14 mg/g FW to 5.29 mg/g FW, TGW-134 increased from 3.46 mg/g FW to 4.56 mg/g FW, TGW-16 increased from 3.77 mg/g FW to 4.52 mg/g FW, HD 2967 (C) increased from 3.26 mg/g FW to 4.54 mg/g FW, GW 322 (C) increased from 3.37 mg/g FW to 4.55 mg/g FW. Overall, four genotype namely, TGW-60, TGW-62, TGW-64 and TGW-68 showed maximum increase of total soluble sugar content from optimum environment to heat stress environment.

So, total soluble sugar content was found to be increased in most of the studied wheat mutant genotypes under heat stress compared to the optimum environment. Similar results have been reported by Sattar *et al.* (2020) and Mohi-Ud-din *et al.* (2021). They suggested that Soluble sugars such as glucose, fructose, and sucrose play a multirole in plants, they act as a primary source of energy and also serve as Osmo protectants and signalling molecules that synchronize expression of genes and stress responses. Similarly, Keunen *et al.* (2013) reported that under heat stress, enhancement in sugar levels contribute to osmotic adjustment, aiding to maintain turgor pressure of the cell and membrane integrity, which are vital for assisting metabolic activity and cellular homeostasis.

The observed enhancement in soluble sugars across all genotypes could thus reflect a productive stress mitigation strategy, permitting the plants to sustain physiological functions and potentially supporting yield stability under terminal heat stress.

In bubble plot, the size of each bubble showed the magnitude or value of the trait for a particular genotype. Colour gradient (green to blue) also reflects the trait value, with darker blues representing higher values (figure 2).

The heat map represented that top Cluster includes elite genotypes such as., TGW-91, TGW-102, TGW-134, TGW-27, and TGW-137, which exhibited strong red signals (high values) for grain yield per plot as well as protein content under heat stress. These are likely heat-tolerant genotypes. Middle Cluster accommodates genotypes like HD 2967 (C), GW 322 (C), TGW-55, TGW-78, etc., which exhibited moderate levels of traits with variegated red and blue shades, showing intermediate responses to heat. While, Bottom Cluster accommodate TGW-88, TGW-101, TGW-103, TGW-74, etc., with dark blue coloration, especially during heat stress conditions, showing low yield and low physiological and biochemical performance. These are probably heat-sensitive genotypes (figure 3).

The correlation matrix showed that traits measured within the same environment, such as total protein, sugar, and chlorophyll, exhibited strong positive correlations, showing consistent expression across conditions. However, during heat stress, grain yield exhibited a negative correlation with total protein and sugar content, showing that higher stress caused biochemical assemblage may reduce yield. Chlorophyll content under heat stress also negatively correlated with protein and sugar levels, indicating a physiological trade-off (figure 4)

Figure 5 represented the pairwise distance matrix heatmap which illustrates the genetic or phenotypic heterogeneity among the 36 wheat genotypes. The matrix utilizes a colour gradient which range from dark blue (low distance/similarity) to bright yellow (high distance/dissimilarity) to visualize the correlation between genotypes. Genotypes such as TGW-27, TGW-91, TGW-102, and TGW-134 showed maximum distances (yellow shades) from most other genotypes, showing distinct phenotypic profiles, possibly because of superior performance during heat stress. Overall, this matrix provides insight into the diversity within the genotype pool and helps to identify genetically or phenotypically divergent lines, which can act as valuable resources in breeding programs focused on enhancement of heat stress tolerance and yield stability in wheat.

Conclusion

The present study involved thirty-four mutant genotypes developed from a single parent variety 'Borlaug 100" using 300Gy gamma irradiation and two check varieties HD-2967 and GW-322. The investigation revealed than the collaborative physiological and biochemical changes recorded in the 36 wheat mutants during heat stress namely, an increase in total chlorophyll, total protein, and total soluble sugars, along with a reduction in carotenoid content reflect a complex but coordinated adjustable response to high-temperature conditions. The increase in chlorophyll content may represent enhanced or sustained photosynthetic performance in tolerant genotypes, while the reduction in carotenoids could be an outcome of oxidative disintegration due to surplus reactive oxygen species. Concurrently, increased in total protein content indicated the enhancement of stress-responsive proteins, which include heat shock proteins, and the increase in soluble sugars indicate their participation in Osmo protection, metabolic regulation, and ROS scavenging. Together, these shifts emphasize the multifaceted mechanisms employed by wheat mutants to mitigate heat-induced damage and sustain physiological homeostasis, offering critical insights for breeding programs aimed at improving heat stress resilience in wheat. Conclusively five genotypes namely., TGW-60, TGW-62, TGW-64, TGW-68 and TGW-74 gave superior biochemical and physiological performance so, they can be utilized further for development of Breeding lines for climate resilient cultivar production.

Table 1: Grain yield per plot, Physiological and Biochemical parameters during Optimum Environment

S. No.	Genotypes	Grain Yield per Plot in optimum environment (g/plot)	Physiological Parameters in Optimum Environment		Biochemical Parameters in Optimum Environment	
			Total Chlorophyll (mg/g)	Total Carotenoid (mg/g)	Total Protein (mg/g FW)	Total Sugar (mg/g FW)
1	TGW-1	665.62	2.23	3.85	4.17	5.09
2	TGW-8	718.59	2.24	3.79	3.22	4.29
3	TGW-10	689.29	2.24	3.86	2.93	4.04
4	TGW-20	669.85	2.29	3.84	4.05	5.1
5	TGW-25	786.33	2.26	3.86	3.18	4.12
6	TGW-27	1144.33	2.46	3.97	2.69	3.76
7	TGW-48	726.33	2.23	3.81	3.01	4.37
8	TGW-55	725.33	2.26	3.86	2.28	3.3
9	TGW-60	734.67	2.25	3.81	2.18	3.27
10	TGW-62	691	2.21	3.84	3.26	4.31
11	TGW-64	724.67	2.14	3.8	3.51	4.02
12	TGW-68	634.33	2.03	3.83	3.6	4.54
13	TGW-69	728.67	2.12	3.82	3.06	4.11
14	TGW-72	690.33	2.13	3.84	2.77	4.59
15	TGW-74	561.67	1.97	2.75	4.2	5.1
16	TGW-78	692	2.08	3.48	4.06	5.19
17	TGW-84	635	2.11	3.8	4.14	5
18	TGW-85	785.33	2.12	3.48	2.91	4.12
19	TGW-88	524	1.96	2.74	4	5.22
20	TGW-90	562.34	2.14	3.81	3.2	4.8
21	TGW-91	1064.67	2.46	3.97	2.31	3.72
22	TGW-92	666.67	2.14	3.79	3.07	4.79
23	TGW-93	724	2.16	3.48	4.08	5.21
24	TGW-101	744.67	1.88	3.49	4.3	5.14
25	TGW-102	1073.33	2.48	3.98	2.24	3.72
26	TGW-103	555.33	2.24	2.73	4.11	5.05
27	TGW-105	764.67	2.11	3.46	2.97	4.12
28	TGW-109	744.67	2.21	3.5	2.71	4.76
29	TGW-110	682.67	2.22	3.47	3.15	4.21
30	TGW-114	751.33	2.25	3.49	2.29	3.44
31	TGW-120	764	2.2	3.46	3.29	4.44
32	TGW-125	728	2.22	3.83	3.12	4.14
33	TGW-134	1118.67	2.47	3.93	2.42	3.46
34	TGW-16	1140	2.46	3.95	2.3	3.77
35	HD 2967 (C)	792	2.21	3.8	2.35	3.26
36	GW 322 (C)	797.67	2.22	3.81	2.27	3.37

Table 2: Grain yield per plot, Physiological and Biochemical parameters during Heat stress Environment

S.No.	Genotypes	Grain Yield per Plot in Heat stress Env. (g/plot)	Physiological Parameters in Heat stress Env.		Biochemical Parameters in Heat stress Env.	
			Total Chlorophyll (mg/g)	Total Carotenoid (mg/g)	Total Protein (mg/g FW)	Total Sugar (mg/g FW)
1	TGW-1	951.67	2.3	2.84	3.17	6.19
2	TGW-8	877.67	2.26	2.87	3.17	6.24
3	TGW-10	869.67	2.31	2.86	3.19	5.98
4	TGW-20	827.67	2.31	3.12	3.19	5.64
5	TGW-25	830.67	2.33	2.82	3.16	5.66
6	TGW-27	1083	2.48	3.7	2.54	4.55
7	TGW-48	844.33	2.25	2.97	4	5.48
8	TGW-55	857.33	2.26	2.81	3.07	5.48
9	TGW-60	347.33	1.54	2.37	5.14	8.87
10	TGW-62	346	1.59	2.33	5.17	8.84
11	TGW-64	345.67	1.52	2.35	5.13	8.85
12	TGW-68	337	1.56	2.35	5.11	8.85
13	TGW-69	880.67	2.27	2.9	3.07	5.43
14	TGW-72	860.33	2.25	2.98	3.23	5.59
15	TGW-74	855.67	2.25	2.96	2.86	5.1
16	TGW-78	784	2.26	2.94	3.24	5.35
17	TGW-84	761.33	2.18	2.92	3.25	5.23
18	TGW-85	765.33	2.22	2.91	3.28	5.49
19	TGW-88	784	2.24	2.92	5.12	8.83
20	TGW-90	779.67	2.18	2.91	3.23	6.19
21	TGW-91	1062.67	2.46	3.79	2.56	4.55
22	TGW-92	759.33	2.2	2.86	2.54	4.56
23	TGW-93	829.33	2.19	2.92	3.21	5.12
24	TGW-101	951.33	2.23	2.92	3.2	5.47
25	TGW-102	1155.67	2.44	3.9	2.56	4.54
26	TGW-103	761.33	2.22	2.96	2.55	4.56
27	TGW-105	841.67	2.26	3.01	2.56	4.53
28	TGW-109	840	2.22	3.05	2.55	4.56
29	TGW-110	799.67	2.21	3.05	3.25	5.5
30	TGW-114	833.67	2.22	3.08	3.13	5.91
31	TGW-120	739	2.22	3.08	3.14	5.19
32	TGW-125	861.67	2.24	3.08	3.29	5.29
33	TGW-134	1059	2.48	3.94	2.56	4.56
34	TGW-16	1249	2.45	3.9	2.53	4.52
35	HD 2967 (C)	837.67	2.25	3.06	2.53	4.54
36	GW 322 (C)	922.67	2.25	3.06	2.54	4.55

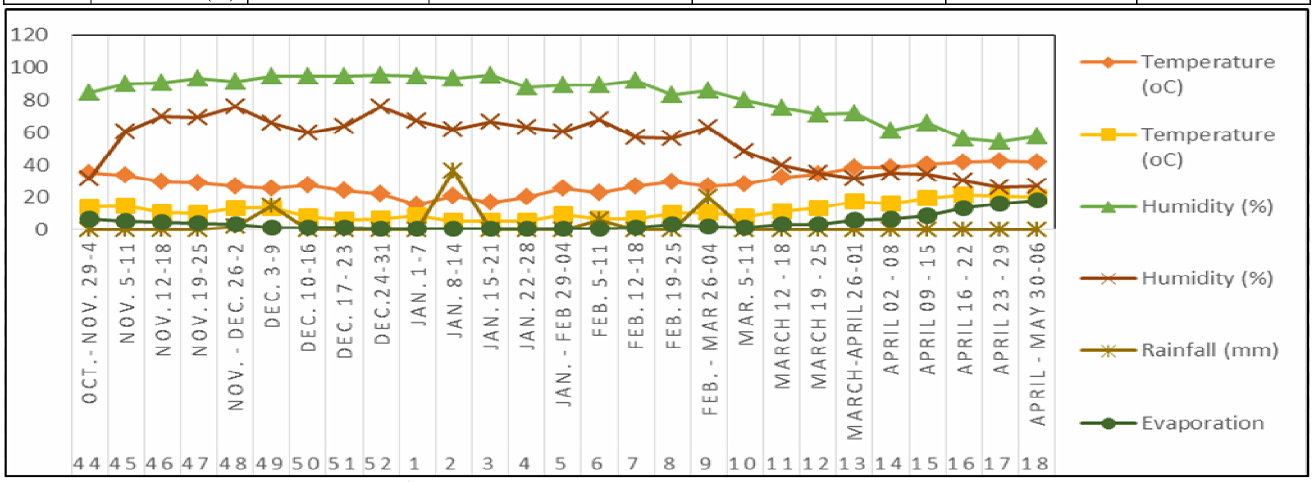

Fig. 1: Weather data on Temperature (˚C), Humidity (%), Rainfall (mm) and evaporation (mm) during Rabi season 2023-24

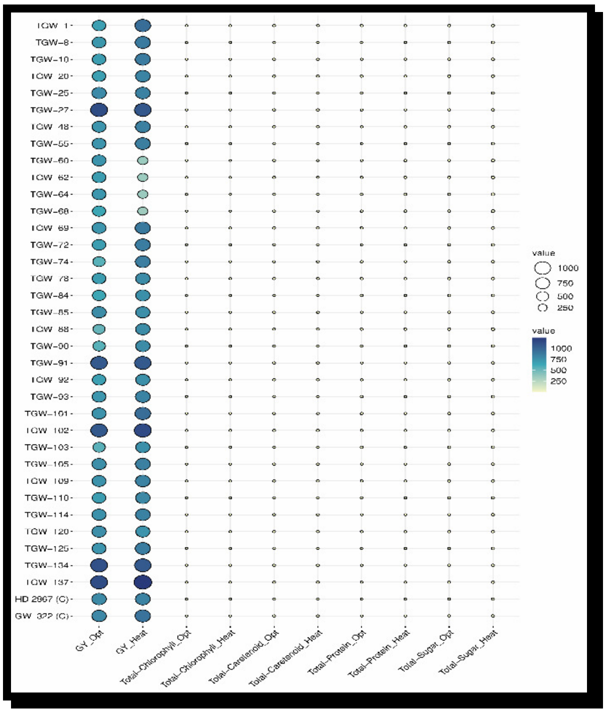

Fig. 2 : Bubble Plot of Morpho-physio and Biochemical parameters in Wheat mutants

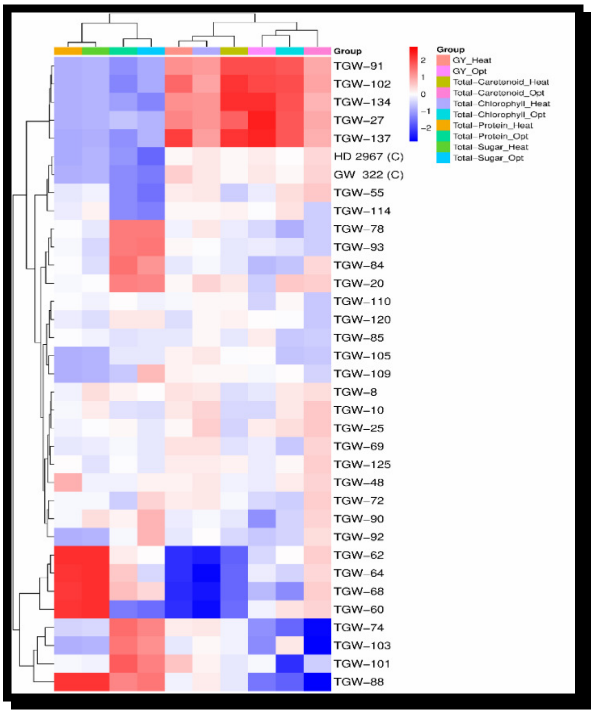

Fig. 3 : Heat map of Morpho-physio and Biochemical parameters in Wheat mutants

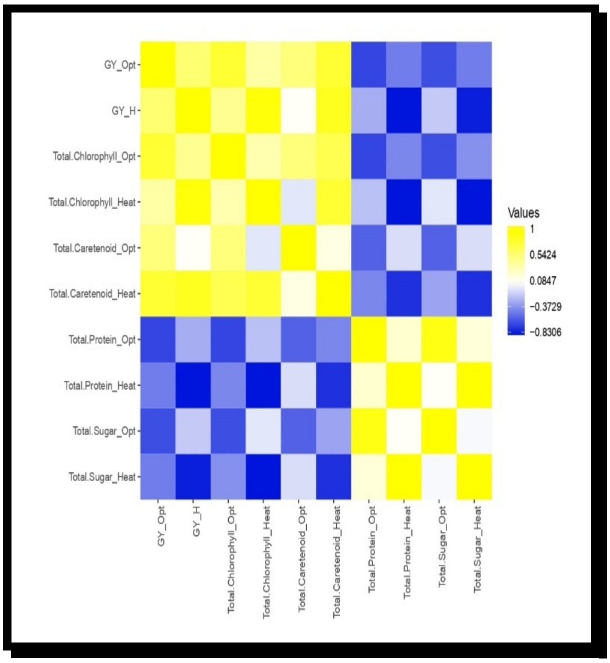

Fig. 4 : Correlation matrix of Morpho-physio and Biochemical parameters in Wheat mutants

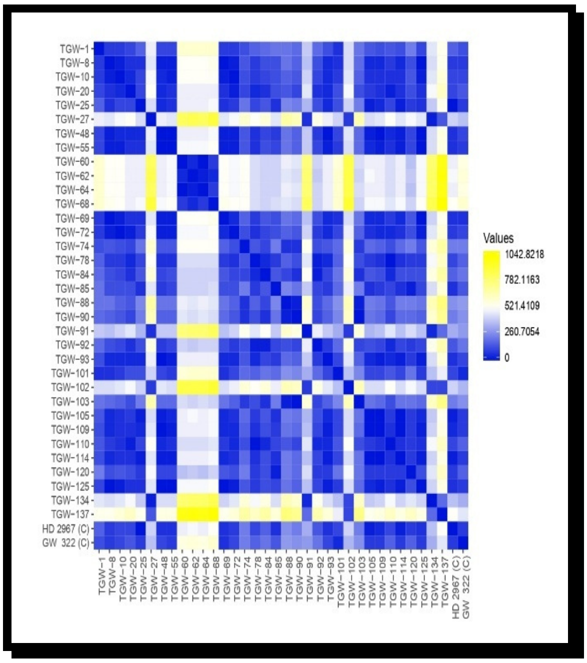

Fig. 5 : Pairwise matrix of Morpho-physio and Biochemical parameters in Wheat mutants

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