Assessment of genetic variability, heritability and genetic advance in wheat (*Triticum aestivum* L.) genotypes under varying temperature conditions.

**ABSTRACT**

One ninety diverse wheat genotypes were evaluated for genetic variability, heritability and genetic advance under under three temperature conditions at the Research Farm of Department of Genetics and Plant Breeding, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India. The genotypes were grown in randomize block design and data were collected for various morpho-agronomic characters. Analysis of observed data showed that the mean squares due to treatments for all the traits in all environments were highly significant. GCV and PCV were highest for canopy temperature depression, grain weight/spike, grain yield/plant and lowest for days to anthesis. Heritability (bs) estimates were high for canopy temperature depression (CTD), followed by yield/plant, grain weight/ spike, grain number /spike, 1000- grain weight, grain yield/plant and lowest for days to heading and days to anthesis in case of both environments. The estimates of genetic advance (GA) were highest for canopy temperature depression followed by grain weight/spike, yield/plant, grain yield/spike, tiller number/plant, grain number/ spike and lowest for days to 50% flowering and days to maturity under all (normal late sown and very late sown) environment. This study suggests that the presence of adequate genetic variability, heritability and genetic advance for these traits under normal and heat stress environment is suitable for breeding programs and crop improvement.

**Keywords:** Analysis of variance, Genetic advance, GCV, Heat stress, Heritability, PCV.

**Introduction**

Wheat (*Triticum aestivum* L.) is the most widely cultivated and consumed cereal crop globally, often referred to as the "king of cereals" due to its significant contribution to human nutrition and food security. It provides nearly 55% of the carbohydrates and 20% of the food calories consumed worldwide. [1] With its adaptability to diverse climates and its role in human and animal nutrition, wheat remains a crucial agricultural commodity. [2]. The primary cultivated wheat variety is hexaploid wheat, commonly known as bread wheat, which is highly valued for bread-making.

The global wheat scenario in 2023-24 indicates a cultivation area of 215 million hectares, yielding around 780 million metric tons, with leading producers including China, India, Russia, and the United States. [3]. In India, wheat is the second most important crop after rice, contributing to 35.5% of total food grain production. [4] The country's wheat production reached 107 million metric tons in 2021-22, with major wheat-producing states being Uttar Pradesh, Punjab, Haryana, and Madhya Pradesh. [5]

Wheat production faces numerous challenges, particularly due to increasing temperature stress caused by global warming. Heat stress significantly affects wheat growth, reducing grain weight, yield, and overall productivity. [6].Studies estimate that a 1°C increase in temperature can lead to a 6% decline in global wheat production. [7] To mitigate these challenges, breeding strategies focus on developing climate-resilient wheat varieties.

The success of a plant breeding program largely depends on the presence of genetic variability within a crop species. The effectiveness of selection is directly influenced by the extent of genetic variation available in the plant population. Therefore, the potential for genetic improvement in any trait is determined by the degree of variability present in the gene pool for that particular trait. Understanding the magnitude of genetic variability within a crop species is crucial for breeders to initiate an efficient and well-planned breeding program [8].

Heritability and genetic advance are key parameters in the selection process. The combined estimation of heritability and genetic advance is generally more useful in predicting selection gains than heritability alone. Heritability measures the proportion of phenotypic variance that can be attributed to genetic factors and serves as a predictive tool in crop breeding [9]. It provides an indication of the genetic gain expected from selection under specific environmental conditions. Higher heritability estimates simplify the selection process, making it easier for breeders to identify superior genotypes [10].

When high heritability (broad sense) is accompanied by high genetic advance, it indicates a strong influence of additive genetic variance in trait expression. Selection based on such traits can significantly contribute to grain yield improvement [11]. Estimating heritability plays a crucial role in identifying elite genotypes from a diverse genetic pool, assisting breeders in making informed selection decisions. The primary objective of this study is to evaluate genetic variability, heritability, and genetic advance under both normal and heat stress conditions. The findings will contribute to future breeding and crop improvement programs aimed at enhancing wheat productivity and resilience.

The present study aims to assess the genetic variability, heritability, and genetic advance in wheat genotypes under normal and heat-stress conditions. This assessment will help identify promising genotypes that can be utilized in breeding programs to develop climate-resilient wheat varieties with stable yield performance.

**Materials and Methods**

The experiment was carried out at Post Graduate Institute Farm, Department of Agricultural, Botany, Mahatma Phule Krishi Vidyapeeth Rahuri, Dist. Ahmednagar (M.S.) India during Rabi 2021-22 and Rabi 2022-23.

Experimental material consisted of 20 wheat genotypes including five checks were obtained from different wheat research from all over India. The experiment was laid out in Randomized Block Design (RBD) in three replications along with three different dates of sowing (1st December, 16th December and 1st January for rabi, season 2021-22 and rabi, season 2022 -23.). Each genotype was planted in four rows by hand, at 2-3 cm depth in soil with spacing of 18 cm between two row. A total of 16 morphological traits based observations were made. Further, observations for days to fifty percent flowering, days to maturity, plant height, spike length, number of spirelets per spike, number of grain per spike, thousand grain weight and grain yield per plant were recorded each of the three environments individually and pooled environments.

Heritability (h2) and genetic advance (GA) were estimated suggested by Allard *et al*. (1960) [12] and variability was estimated by the Burton and De Vane (1953) [13].

**RESULTS AND DISCUSSION**

**Table: 1 Variability Parameters of twenty wheat genotypes for yield and yield contributing traits in 1st sowing- 1st Dec. 2021 (S1)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h² (Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **81.07** | 69.13 | 89.60 | 5.69 | 7.93 | 5.52 | 51.43 | 6.81 | 8.40 |
|  | Days to 50 % flowering | **66.57** | 53.67 | 75.00 | 6.93 | 7.49 | 2.85 | 85.58 | 8.79 | 13.21 |
|  | Days to maturity | **113.25** | 103.67 | 135.33 | 6.65 | 6.83 | 1.55 | 94.83 | 15.11 | 13.34 |
|  | Earhead length | **10.33** | 7.95 | 12.79 | 12.33 | 14.25 | 7.14 | 74.92 | 2.27 | 21.99 |
|  | Spikelets per spike | **15.99** | 13.43 | 19.17 | 9.52 | 14.02 | 10.30 | 46.08 | 2.13 | 13.31 |
|  | Grains per spike | **46.82** | 37.60 | 57.87 | 8.96 | 12.46 | 8.66 | 51.66 | 6.21 | 13.26 |
|  | Yield per Plant | **18.09** | 11.18 | 26.61 | 21.41 | 25.22 | 13.32 | 72.12 | 6.78 | 37.46 |
|  | Canopy Temperature Depression | **4.89** | 1.80 | 7.33 | 35.54 | 36.82 | 9.65 | 93.13 | 3.45 | 70.64 |
|  | 1000 grain weight | **40.94** | 36.51 | 43.93 | 4.47 | 8.11 | 6.76 | 30.39 | 2.08 | 5.07 |
|  | Yield/ plot | **1035.94** | 698.71 | 1367.31 | 17.99 | 19.82 | 8.31 | 82.43 | 348.58 | 33.65 |
|  | Dry Matter at 30days | **0.66** | 0.51 | 0.86 | 15.45 | 15.77 | 3.15 | 96.02 | 0.21 | 31.19 |
|  | Dry Matter at 60days | **6.58** | 5.47 | 7.83 | 10.04 | 12.31 | 7.13 | 66.51 | 1.11 | 16.87 |
|  | Dry Matter at 90days | **12.18** | 10.23 | 13.84 | 6.49 | 11.36 | 9.32 | 32.68 | 0.93 | 7.65 |
|  | Absolute growth rate for days 30-60 | **0.20** | 0.16 | 0.23 | 9.99 | 12.01 | 6.66 | 69.23 | 0.03 | 17.13 |
|  | Absolute growth rate for days 60-90 | **0.19** | 0.15 | 0.21 | 6.64 | 10.87 | 8.60 | 37.37 | 0.02 | 8.37 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.04 | 1.59 | 5.77 | 5.55 | 7.55 | 0.02 | 0.90 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 7.37 | 8.77 | 4.76 | 70.53 | 0.00 | 12.75 |
|  | Pollen viability | **88.22** | 82.20 | 95.43 | 3.22 | 5.13 | 4.00 | 39.27 | 3.66 | 4.15 |
|  | PSII sensitivity | **0.76** | 0.69 | 0.85 | 4.76 | 7.11 | 5.27 | 44.92 | 0.05 | 6.58 |
|  | Photosynthetic rate | **15.97** | 9.61 | 23.75 | 25.25 | 28.34 | 12.85 | 79.43 | 7.40 | 46.36 |
|  | Fructan content at pre anthesis stage | **3.67** | 3.03 | 5.17 | 16.85 | 17.20 | 3.42 | 96.04 | 1.25 | 34.02 |
|  | Fructan content at post anthesis stage | **1.12** | 0.67 | 1.55 | 17.19 | 17.77 | 4.50 | 93.60 | 0.38 | 34.27 |
|  | Reducing sugar at pre anthesis stage | **10.16** | 8.37 | 12.34 | 11.03 | 11.47 | 3.15 | 92.44 | 2.22 | 21.85 |
|  | Reducing sugar at post anthesis stage | **3.71** | 2.41 | 5.58 | 28.92 | 29.97 | 7.85 | 93.14 | 2.13 | 57.50 |
|  | Non-Reducing sugar at pre anthesis stage | **1.36** | 0.98 | 1.93 | 21.19 | 21.44 | 3.29 | 97.65 | 0.59 | 43.13 |
|  | Non-Reducing sugar at post anthesis stage | **0.50** | 0.25 | 0.85 | 31.03 | 31.49 | 5.39 | 97.07 | 0.31 | 62.97 |
|  | Total sugar at pre anthesis stage | **11.52** | 9.35 | 14.24 | 12.12 | 12.45 | 2.85 | 94.74 | 2.80 | 24.30 |
|  | Total sugar at post anthesis stage | **4.21** | 2.68 | 6.42 | 29.08 | 29.86 | 6.77 | 94.85 | 2.45 | 58.34 |
|  | Senescence Rate | **3.23** | 1.33 | 4.67 | 31.74 | 35.26 | 15.36 | 81.04 | 1.90 | 58.87 |

**Table: 2 Variability parameters of twenty wheat genotypes for yield and yield contributing traits in 2nd sowing- 16th Dec. 2021 (S2)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h² (Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **76.85** | 70.58 | 90.13 | 7.24 | 7.51 | 2.01 | 92.83 | 11.04 | 14.37 |
|  | Days to 50 % flowering | **61.33** | 53.00 | 66.67 | 4.92 | 6.62 | 4.42 | 55.36 | 4.63 | 7.55 |
|  | Days to maturity | **107.15** | 99.33 | 128.67 | 6.73 | 6.83 | 1.19 | 96.96 | 14.62 | 13.65 |
|  | Earhead length | **10.17** | 8.56 | 12.40 | 12.34 | 14.47 | 7.57 | 72.64 | 2.20 | 21.66 |
|  | Spikelets per spike | **15.07** | 11.90 | 18.18 | 10.90 | 12.85 | 6.80 | 71.97 | 2.87 | 19.06 |
|  | Grains per spike | **47.20** | 42.40 | 51.70 | 2.94 | 8.10 | 7.55 | 13.20 | 1.04 | 2.20 |
|  | Yield per Plant | **12.51** | 9.55 | 17.96 | 18.28 | 19.35 | 6.33 | 89.29 | 4.45 | 35.59 |
|  | Canopy Temperature Depression | **3.64** | 0.47 | 8.17 | 70.86 | 72.95 | 17.35 | 94.34 | 5.17 | 41.78 |
|  | 1000 grain weight | **37.77** | 33.84 | 42.48 | 4.65 | 7.84 | 6.31 | 35.13 | 2.14 | 5.67 |
|  | Yield/ plot | **828.50** | 630.58 | 1137.05 | 14.89 | 17.65 | 9.49 | 71.12 | 214.25 | 25.86 |
|  | Dry Matter at 30days | **0.56** | 0.44 | 0.74 | 15.91 | 16.59 | 4.68 | 92.03 | 0.18 | 31.44 |
|  | Dry Matter at 60days | **5.64** | 4.18 | 6.97 | 14.71 | 15.32 | 4.30 | 92.11 | 1.64 | 29.07 |
|  | Dry Matter at 90days | **10.62** | 8.98 | 11.84 | 8.14 | 8.99 | 3.82 | 81.97 | 1.61 | 15.18 |
|  | Absolute growth rate for days 30-60 | **0.17** | 0.12 | 0.21 | 15.04 | 15.11 | 1.41 | 99.13 | 0.05 | 30.86 |
|  | Absolute growth rate for days 60-90 | **0.15** | 0.13 | 0.18 | 6.98 | 8.10 | 4.11 | 74.23 | 0.02 | 12.38 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.04 | 2.58 | 3.31 | 2.07 | 60.72 | 0.03 | 4.14 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 10.74 | 12.59 | 6.55 | 72.88 | 0.02 | 18.90 |
|  | Pollen viability | **86.12** | 79.08 | 94.58 | 5.09 | 5.24 | 1.21 | 94.69 | 8.79 | 10.21 |
|  | PSII sensitivity | **0.73** | 0.65 | 0.80 | 7.50 | 7.83 | 2.25 | 91.78 | 0.11 | 14.80 |
|  | Photosynthetic rate | **12.86** | 6.94 | 20.90 | 33.13 | 33.56 | 5.32 | 97.49 | 8.67 | 67.39 |
|  | Fructan content at pre anthesis stage | **3.28** | 2.20 | 5.17 | 25.34 | 25.61 | 3.70 | 97.91 | 1.69 | 51.65 |
|  | Fructan content at post anthesis stage | **0.93** | 0.54 | 1.45 | 28.18 | 28.35 | 3.05 | 98.85 | 0.54 | 57.72 |
|  | Reducing sugar at pre anthesis stage | **9.02** | 7.45 | 10.65 | 10.82 | 11.37 | 3.51 | 90.47 | 1.91 | 21.20 |
|  | Reducing sugar at post anthesis stage | **2.92** | 1.51 | 4.56 | 29.03 | 30.83 | 10.38 | 88.66 | 1.64 | 56.31 |
|  | Non-Reducing sugar at pre anthesis stage | **1.34** | 0.81 | 4.30 | 18.03 | 93.99 | 92.24 | 3.68 | 0.10 | 7.13 |
|  | Non-Reducing sugar at post anthesis stage | **0.46** | 0.22 | 0.75 | 32.99 | 33.36 | 4.96 | 97.79 | 0.31 | 67.21 |
|  | Total sugar at pre anthesis stage | **10.37** | 8.25 | 12.36 | 10.61 | 15.83 | 11.75 | 44.92 | 1.52 | 14.65 |
|  | Total sugar at post anthesis stage | **3.38** | 1.86 | 5.28 | 29.11 | 30.50 | 9.11 | 91.07 | 1.93 | 57.22 |
|  | Senescence Rate | **3.13** | 1.33 | 4.67 | 31.18 | 35.37 | 16.70 | 77.71 | 1.77 | 56.62 |

**Table: 3 Variability parameters of twenty wheat genotypes for yield and yield contributing traits in 3rd sowing- 1st  Jan. 2022 (S3)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h² (Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **72.34** | 66.57 | 85.36 | 5.89 | 8.53 | 6.17 | 47.69 | 6.06 | 8.38 |
|  | Days to 50 % flowering | **56.49** | 50.33 | 62.67 | 5.30 | 7.48 | 5.27 | 50.25 | 4.37 | 7.74 |
|  | Days to maturity | **101.55** | 95.33 | 108.00 | 3.16 | 4.48 | 3.17 | 49.85 | 4.67 | 4.60 |
|  | Earhead length | **9.51** | 8.05 | 11.49 | 8.82 | 10.71 | 6.07 | 67.84 | 1.42 | 14.96 |
|  | Spikelets per spike | **13.85** | 10.60 | 16.47 | 11.97 | 13.17 | 5.49 | 82.64 | 3.11 | 22.42 |
|  | Grains per spike | **38.62** | 32.33 | 44.70 | 9.32 | 13.97 | 10.41 | 44.52 | 4.95 | 12.81 |
|  | Yield per Plant | **10.50** | 7.00 | 15.31 | 21.12 | 23.48 | 10.25 | 80.95 | 4.11 | 39.15 |
|  | Canopy Temperature Depression | **2.82** | 0.47 | 6.17 | 72.20 | 74.73 | 19.28 | 93.35 | 4.05 | 143.71 |
|  | 1000 grain weight | **34.82** | 32.75 | 41.13 | 4.92 | 9.34 | 7.94 | 27.75 | 1.86 | 5.34 |
|  | Yield/ plot | **605.14** | 519.86 | 833.46 | 13.29 | 15.36 | 7.69 | 74.93 | 143.42 | 23.70 |
|  | Dry Matter at 30days | **0.50** | 0.34 | 0.68 | 17.00 | 19.17 | 8.85 | 78.66 | 0.16 | 31.06 |
|  | Dry Matter at 60days | **4.95** | 4.12 | 5.94 | 13.29 | 13.36 | 1.37 | 98.95 | 1.35 | 27.23 |
|  | Dry Matter at 90days | **8.69** | 7.40 | 10.02 | 9.14 | 9.24 | 1.32 | 97.96 | 1.62 | 18.64 |
|  | Absolute growth rate for days 30-60 | **0.15** | 0.12 | 0.18 | 12.98 | 13.10 | 1.74 | 98.24 | 0.04 | 26.50 |
|  | Absolute growth rate for days 60-90 | **0.12** | 0.11 | 0.14 | 5.56 | 6.61 | 3.59 | 70.58 | 0.01 | 9.62 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.04 | 2.51 | 4.84 | 4.14 | 26.77 | 0.02 | 2.67 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 8.29 | 9.01 | 3.51 | 84.78 | 0.03 | 15.73 |
|  | Pollen viability | **82.14** | 76.27 | 88.27 | 3.90 | 4.14 | 1.37 | 89.00 | 6.23 | 7.59 |
|  | PSII sensitivity | **0.69** | 0.61 | 0.77 | 7.24 | 7.61 | 2.36 | 90.35 | 0.10 | 14.17 |
|  | Photosynthetic rate | **11.10** | 5.54 | 18.60 | 32.77 | 33.82 | 8.33 | 93.93 | 7.27 | 65.43 |
|  | Fructan content at pre anthesis stage | **3.15** | 1.87 | 5.13 | 28.45 | 28.60 | 2.93 | 98.95 | 1.84 | 58.30 |
|  | Fructan content at post anthesis stage | **0.88** | 0.57 | 1.15 | 21.19 | 21.63 | 4.33 | 95.99 | 0.37 | 42.78 |
|  | Reducing sugar at pre anthesis stage | **7.71** | 6.29 | 9.50 | 13.14 | 13.83 | 4.32 | 90.24 | 1.98 | 25.71 |
|  | Reducing sugar at post anthesis stage | **2.32** | 1.40 | 3.50 | 27.14 | 29.73 | 12.12 | 83.39 | 1.18 | 51.06 |
|  | Non-Reducing sugar at pre anthesis stage | **1.14** | 0.79 | 1.81 | 24.73 | 24.85 | 2.43 | 99.05 | 0.58 | 50.70 |
|  | Non-Reducing sugar at post anthesis stage | **0.41** | 0.21 | 0.71 | 33.65 | 34.02 | 5.05 | 97.79 | 0.28 | 68.54 |
|  | Total sugar at pre anthesis stage | **8.85** | 7.20 | 11.31 | 14.44 | 14.91 | 3.68 | 93.90 | 2.55 | 28.83 |
|  | Total sugar at post anthesis stage | **2.73** | 1.64 | 4.21 | 27.59 | 29.48 | 10.37 | 87.62 | 1.45 | 53.21 |
|  | Senescence Rate | **3.10** | 1.33 | 4.67 | 36.94 | 40.69 | 17.06 | 82.41 | 2.14 | 69.08 |

**Table: 4 Variability parameters of twenty wheat genotypes for yield and yield contributing traits in 1st sowing- 1st Dec. 2022 (S1)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h² (Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **79.90** | 71.40 | 90.40 | 5.27 | 8.30 | 6.41 | 40.29 | 5.50 | 6.89 |
|  | Days to 50 % flowering | **65.83** | 55.00 | 74.00 | 6.27 | 8.40 | 5.59 | 55.77 | 6.36 | 9.65 |
|  | Days to maturity | **112.22** | 102.00 | 130.00 | 5.81 | 6.43 | 2.75 | 81.71 | 12.15 | 10.82 |
|  | Earhead length | **10.36** | 8.30 | 12.53 | 11.45 | 13.78 | 7.67 | 69.04 | 2.03 | 19.60 |
|  | Spikelets per spike | **15.68** | 12.73 | 18.40 | 11.23 | 11.95 | 4.08 | 88.35 | 3.41 | 21.75 |
|  | Grains per spike | **47.10** | 37.07 | 54.93 | 9.45 | 9.99 | 3.24 | 89.47 | 8.68 | 18.42 |
|  | Yield per Plant | **17.74** | 11.01 | 23.78 | 21.30 | 21.77 | 4.51 | 95.72 | 7.62 | 42.93 |
|  | Canopy Temperature Depression | **4.00** | 0.40 | 8.40 | 53.40 | 54.10 | 8.70 | 97.42 | 4.34 | 108.57 |
|  | 1000 grain weight | **40.95** | 35.22 | 46.23 | 5.77 | 6.68 | 3.38 | 74.47 | 4.20 | 10.25 |
|  | Yield/ plot | **1172.83** | 821.85 | 1473.59 | 18.64 | 19.55 | 5.89 | 90.91 | 429.42 | 36.61 |
|  | Dry Matter at 30days | **0.67** | 0.42 | 0.90 | 19.76 | 24.91 | 15.16 | 62.97 | 0.22 | 32.31 |
|  | Dry Matter at 60days | **6.71** | 5.36 | 8.03 | 11.63 | 12.50 | 4.59 | 86.52 | 1.49 | 22.28 |
|  | Dry Matter at 90days | **12.16** | 10.09 | 13.66 | 8.44 | 9.08 | 3.36 | 86.27 | 1.96 | 16.14 |
|  | Absolute growth rate for days 30-60 | **0.20** | 0.16 | 0.24 | 11.99 | 14.62 | 8.36 | 67.29 | 0.04 | 20.27 |
|  | Absolute growth rate for days 60-90 | **0.18** | 0.15 | 0.20 | 6.92 | 9.74 | 6.85 | 50.55 | 0.02 | 10.14 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.04 | 3.42 | 10.31 | 9.73 | 10.99 | 0.0008 | 2.33 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 7.54 | 10.38 | 7.13 | 52.77 | 0.0010 | 11.28 |
|  | Pollen viability | **88.37** | 81.28 | 95.45 | 4.68 | 4.96 | 1.63 | 89.18 | 8.05 | 9.11 |
|  | PSII sensitivity | **0.76** | 0.70 | 0.84 | 4.92 | 5.50 | 2.46 | 80.00 | 0.07 | 9.07 |
|  | Photosynthetic rate | **15.80** | 9.69 | 22.08 | 24.25 | 25.31 | 7.25 | 91.79 | 7.56 | 47.85 |
|  | Fructan content at pre anthesis stage | **3.63** | 3.00 | 5.10 | 16.27 | 16.74 | 3.91 | 94.54 | 1.18 | 32.59 |
|  | Fructan content at post anthesis stage | **1.12** | 0.63 | 1.58 | 19.56 | 19.73 | 2.55 | 98.32 | 0.45 | 39.95 |
|  | Reducing sugar at pre anthesis stage | **9.98** | 8.34 | 12.36 | 10.60 | 10.74 | 1.72 | 97.43 | 2.15 | 21.55 |
|  | Reducing sugar at post anthesis stage | **3.78** | 2.47 | 5.68 | 27.69 | 28.28 | 5.73 | 95.90 | 2.11 | 55.87 |
|  | Non-Reducing sugar at pre anthesis stage | **1.34** | 0.95 | 1.91 | 21.26 | 22.85 | 8.38 | 86.56 | 0.55 | 40.74 |
|  | Non-Reducing sugar at post anthesis stage | **0.50** | 0.25 | 0.85 | 30.79 | 32.05 | 8.89 | 92.30 | 0.30 | 60.94 |
|  | Total sugar at pre anthesis stage | **11.32** | 9.37 | 14.25 | 11.63 | 11.80 | 1.99 | 97.17 | 2.67 | 23.62 |
|  | Total sugar at post anthesis stage | **4.27** | 2.86 | 6.50 | 27.92 | 28.37 | 5.06 | 96.82 | 2.42 | 56.59 |
|  | Senescence Rate | **3.37** | 1.33 | 5.00 | 34.80 | 38.41 | 16.25 | 82.11 | 2.19 | 64.96 |

**Table No: 5 Variability parameters of twenty wheat genotypes for yield and yield contributing traits in 2nd sowing- 16th Dec. 2021 (S2)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h² (Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **75.87** | 69.73 | 89.77 | 6.51 | 8.62 | 5.65 | 57.09 | 7.69 | 10.13 |
|  | Days to 50 % flowering | **61.25** | 55.00 | 66.00 | 3.83 | 7.25 | 6.16 | 27.90 | 2.55 | 4.17 |
|  | Days to maturity | **106.22** | 98.67 | 128.00 | 6.54 | 7.65 | 3.96 | 73.12 | 12.24 | 11.52 |
|  | Earhead length | **9.89** | 7.91 | 11.20 | 10.06 | 11.89 | 6.34 | 71.60 | 1.74 | 17.54 |
|  | Spikelets per spike | **15.11** | 11.30 | 18.57 | 13.31 | 14.46 | 5.65 | 84.75 | 3.81 | 25.24 |
|  | Grains per spike | **46.87** | 42.23 | 51.50 | 4.79 | 5.46 | 2.62 | 76.95 | 4.06 | 8.66 |
|  | Yield per Plant | **12.44** | 9.15 | 17.30 | 18.80 | 20.32 | 7.71 | 85.60 | 4.46 | 35.83 |
|  | Canopy Temperature Depression | **3.70** | 0.30 | 8.53 | 69.56 | 70.03 | 8.10 | 98.66 | 5.26 | 142.34 |
|  | 1000 grain weight | **38.42** | 34.49 | 43.12 | 6.17 | 7.14 | 3.60 | 74.61 | 4.22 | 10.98 |
|  | Yield/ plot | **932.12** | 633.26 | 1301.18 | 20.22 | 21.63 | 7.68 | 87.39 | 362.96 | 38.94 |
|  | Dry Matter at 30days | **0.67** | 0.35 | 0.92 | 27.96 | 28.89 | 7.25 | 93.70 | 0.37 | 55.76 |
|  | Dry Matter at 60days | **5.70** | 4.20 | 7.12 | 15.11 | 15.42 | 3.09 | 96.00 | 1.74 | 30.50 |
|  | Dry Matter at 90days | **10.61** | 9.05 | 12.00 | 8.20 | 8.51 | 2.27 | 92.88 | 1.73 | 16.28 |
|  | Absolute growth rate for days 30-60 | **0.17** | 0.12 | 0.21 | 14.93 | 15.19 | 2.79 | 96.62 | 0.05 | 30.23 |
|  | Absolute growth rate for days 60-90 | **0.16** | 0.15 | 0.19 | 4.41 | 9.25 | 8.13 | 22.75 | 0.01 | 4.33 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.04 | 11.37 | 14.21 | 15.48 | 18.82 | 0.01 | -5.51 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 12.07 | 14.77 | 8.51 | 66.79 | 0.02 | 20.32 |
|  | Pollen viability | **85.93** | 78.44 | 95.35 | 5.42 | 5.56 | 1.26 | 94.86 | 9.34 | 10.87 |
|  | PSII sensitivity | **0.72** | 0.64 | 0.81 | 7.75 | 7.92 | 1.63 | 95.78 | 0.11 | 15.63 |
|  | Photosynthetic rate | **13.85** | 7.30 | 20.62 | 33.17 | 33.77 | 6.30 | 96.52 | 9.30 | 67.14 |
|  | Fructan content at pre anthesis stage | **3.35** | 2.40 | 4.83 | 21.93 | 22.25 | 3.79 | 97.11 | 1.49 | 44.52 |
|  | Fructan content at post anthesis stage | **0.94** | 0.53 | 1.45 | 29.72 | 31.77 | 11.23 | 87.52 | 0.54 | 57.28 |
|  | Reducing sugar at pre anthesis stage | **8.86** | 7.37 | 10.56 | 11.71 | 11.96 | 2.42 | 95.89 | 2.09 | 23.62 |
|  | Reducing sugar at post anthesis stage | **2.93** | 1.53 | 4.56 | 28.55 | 31.13 | 12.40 | 84.14 | 1.58 | 53.95 |
|  | Non-Reducing sugar at pre anthesis stage | **1.18** | 0.82 | 1.84 | 24.54 | 24.83 | 3.78 | 97.68 | 0.59 | 49.97 |
|  | Non-Reducing sugar at post anthesis stage | **0.46** | 0.22 | 0.75 | 32.88 | 33.25 | 4.94 | 97.79 | 0.31 | 66.98 |
|  | Total sugar at pre anthesis stage | **10.04** | 8.18 | 12.23 | 12.89 | 13.04 | 1.98 | 97.71 | 2.64 | 26.25 |
|  | Total sugar at post anthesis stage | **3.39** | 1.88 | 5.28 | 28.71 | 30.71 | 10.88 | 87.44 | 1.87 | 55.31 |
|  | Senescence Rate | **3.17** | 1.00 | 4.67 | 36.60 | 39.66 | 15.28 | 85.15 | 2.20 | 69.57 |

**Table No: 6 Varvariability of twenty wheat genotypes for yield and yield contributing traits in 3rd sowing- 1st  Jan. 2022 (S3)**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Character** | **Mean** | **Range** | | **GCV (%)** | **PCV (%)** | **ECV (%)** | **h²**  **(Broad Sense)** | **GA at 5%** | **Gen.Adv as % of Mean 5%** |
| **Max** | **Min** |
|  | Plant height | **68.63** | 61.30 | 77.57 | 7.12 | 7.56 | 2.55 | 88.61 | 9.48 | 13.81 |
|  | Days to 50 % flowering | **56.30** | 49.67 | 62.33 | 6.70 | 7.11 | 2.39 | 88.75 | 7.32 | 13.01 |
|  | Days to maturity | **101.02** | 94.00 | 105.33 | 3.35 | 3.54 | 1.16 | 89.31 | 6.59 | 6.52 |
|  | Earhead length | **9.80** | 8.57 | 11.26 | 6.98 | 10.82 | 8.27 | 41.59 | 0.91 | 9.27 |
|  | Spikelets per spike | **13.74** | 11.30 | 15.93 | 9.84 | 11.68 | 6.29 | 70.97 | 2.35 | 17.07 |
|  | Grains per spike | **39.30** | 33.07 | 47.20 | 9.64 | 10.87 | 5.03 | 78.57 | 6.92 | 17.60 |
|  | Yield per Plant | **10.12** | 7.31 | 15.57 | 23.36 | 24.31 | 6.74 | 92.32 | 4.68 | 46.24 |
|  | Canopy Temperature Depression | **2.62** | 0.37 | 6.07 | 73.28 | 78.11 | 27.03 | 88.03 | 3.71 | 141.63 |
|  | 1000 grain weight | **35.61** | 30.72 | 39.93 | 8.34 | 9.11 | 3.67 | 83.77 | 5.60 | 15.72 |
|  | Yield/ plot | **721.79** | 473.71 | 972.19 | 18.25 | 19.93 | 8.00 | 83.89 | 248.53 | 34.43 |
|  | Dry Matter at 30days | **0.55** | 0.41 | 0.82 | 12.27 | 27.31 | 24.40 | 20.19 | 0.06 | 11.36 |
|  | Dry Matter at 60days | **5.01** | 4.15 | 6.02 | 13.19 | 13.26 | 1.34 | 98.98 | 1.35 | 27.04 |
|  | Dry Matter at 90days | **8.73** | 7.44 | 10.06 | 9.10 | 9.19 | 1.31 | 97.96 | 1.62 | 18.55 |
|  | Absolute growth rate for days 30-60 | **0.15** | 0.12 | 0.18 | 12.93 | 13.38 | 3.42 | 93.45 | 0.04 | 25.75 |
|  | Absolute growth rate for days 60-90 | **0.12** | 0.11 | 0.14 | 5.88 | 6.92 | 3.64 | 72.33 | 0.01 | 10.30 |
|  | Relative growth rate for days 30-60 | **0.03** | 0.03 | 0.03 | 9.34 | 11.80 | 13.02 | 21.73 | 0.02 | -5.28 |
|  | Relative growth rate for days 60-90 | **0.01** | 0.01 | 0.01 | 8.56 | 9.23 | 3.46 | 85.96 | 0.02 | 16.35 |
|  | Pollen viability | **82.26** | 75.35 | 88.30 | 4.53 | 4.82 | 1.66 | 88.10 | 7.20 | 8.76 |
|  | PSII sensitivity | **0.70** | 0.61 | 0.78 | 8.71 | 9.07 | 2.52 | 92.29 | 0.12 | 17.23 |
|  | Photosynthetic rate | **11.07** | 5.56 | 16.96 | 32.50 | 33.00 | 5.71 | 97.00 | 7.30 | 65.94 |
|  | Fructan content at pre anthesis stage | **3.13** | 2.10 | 4.73 | 25.83 | 26.07 | 3.52 | 98.18 | 1.65 | 52.73 |
|  | Fructan content at post anthesis stage | **0.89** | 0.57 | 1.17 | 20.39 | 20.78 | 3.98 | 96.33 | 0.37 | 41.23 |
|  | Reducing sugar at pre anthesis stage | **7.79** | 6.43 | 9.54 | 10.88 | 12.01 | 5.10 | 82.01 | 1.58 | 20.30 |
|  | Reducing sugar at post anthesis stage | **2.34** | 1.43 | 3.58 | 27.18 | 29.74 | 12.06 | 83.55 | 1.20 | 51.19 |
|  | Non-Reducing sugar at pre anthesis stage | **1.14** | 0.77 | 1.84 | 25.08 | 25.23 | 2.76 | 98.80 | 0.59 | 51.35 |
|  | Non-Reducing sugar at post anthesis stage | **0.41** | 0.21 | 0.71 | 33.62 | 33.99 | 5.05 | 97.79 | 0.28 | 68.48 |
|  | Total sugar at pre anthesis stage | **8.93** | 7.29 | 11.22 | 12.32 | 13.06 | 4.32 | 89.06 | 2.14 | 23.95 |
|  | Total sugar at post anthesis stage | **2.75** | 1.67 | 4.29 | 27.67 | 29.56 | 10.39 | 87.65 | 1.47 | 53.36 |
|  | Senescence Rate | **3.18** | 1.00 | 4.67 | 38.13 | 41.81 | 17.13 | 83.21 | 2.28 | 71.66 |

Variability

Understanding genetic variability among wheat genotypes is fundamental for effective breeding programs. The success of future wheat improvement efforts depends on the availability of genetic variability to enhance productivity and sustainability. Developing cultivars with a diverse genetic base is crucial to mitigating the adverse effects of heat stress, which significantly impacts yield-related traits.

The estimates of mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and other variability parameters for different sowing conditions across two seasons are presented in Tables 1 to 6. A wide range of values was observed for all characters, indicating substantial genetic variability. The PCV values were consistently higher than the corresponding GCV values for all traits, suggesting the influence of environmental factors.

For rabi season 2021-22, Under normal sowing conditions (S1), the highest GCV values were observed for canopy temperature depression (35.54%), photosynthetic rate (25.25%), reducing sugar at post-anthesis (28.92%), and non-reducing sugar at post-anthesis (31.03%)​. Under heat stress conditions (S2 and S3), higher estimates of GCV were recorded for canopy temperature depression (70.86% in S2, 72.20% in S3), photosynthetic rate (33.13% in S2, 32.77% in S3), and fructan content at pre- and post-anthesis stages (25.34% and 28.18% in S2, 28.45% and 21.19% in S3, respectively)​.

For rabi season 2022-23, similar trend was observed in the second season, where high GCV values were recorded for canopy temperature depression (53.40% in S1, 69.56% in S2, 73.28% in S3), photosynthetic rate (24.25% in S1, 33.17% in S2, 32.50% in S3), and fructan content at pre- and post-anthesis stages (16.27% and 19.56% in S1, 21.93% and 29.72% in S2, 25.83% and 20.39% in S3)​.

The high estimates of PCV and GCV for these traits indicate sufficient genetic variability, suggesting that selection can effectively improve these traits. The presence of considerable variability among genotypes suggests the feasibility of breeding for heat tolerance by targeting traits such as canopy temperature depression, fructan content, and sugar metabolism under stress conditions. These findings align with those reported by Das et al. (2024) [14]. and Parveen et al. (2021) [15] who observed high variability in wheat genotypes for similar traits​.

Heritability and Expected Genetic Advance

Heritability and genetic advance are critical parameters in selecting superior genotypes for wheat improvement. High heritability indicates that genetic factors play a significant role in trait expression, reducing environmental influence and enhancing selection efficiency.

The estimates of heritability and genetic advance under different sowing conditions are presented in Tables 1 to 6.

For rabi season 2021-22, In normal sowing conditions (S1), high heritability was recorded for traits such as days to maturity (94.83%), yield per plant (72.12%), dry matter at 30 days (96.02%), fructan content at pre-anthesis (96.04%), and fructan content at post-anthesis (93.60%)​. Under heat stress conditions (S2 and S3), the highest heritability values were observed for canopy temperature depression (94.34% in S2, 93.35% in S3), photosynthetic rate (97.49% in S2, 93.93% in S3), and fructan content at pre- and post-anthesis stages (97.91% and 98.85% in S2, 98.95% and 95.99% in S3, respectively)​.

For rabi season 2022-23, A similar trend was observed in the second season, where high heritability values were recorded for canopy temperature depression (97.42% in S1, 98.66% in S2, 88.03% in S3), photosynthetic rate (91.79% in S1, 96.52% in S2, 97.00% in S3), and fructan content at pre- and post-anthesis stages (94.54% and 98.32% in S1, 97.11% and 87.52% in S2, 98.18% and 96.33% in S3)​.

High heritability coupled with high genetic advance as a percentage of the mean was observed for canopy temperature depression (70.64% in S1, 41.78% in S2, 143.71% in S3 for 2021-22; 108.57% in S1, 142.34% in S2, 141.63% in S3 for 2022-23), yield per plant (37.46% in S1, 35.59% in S2, 39.15% in S3 for 2021-22; 42.93% in S1, 35.83% in S2, 46.24% in S3 for 2022-23), and fructan content at post-anthesis (34.27% in S1, 57.72% in S2, 42.78% in S3 for 2021-22; 39.95% in S1, 57.28% in S2, 41.23% in S3 for 2022-23)​.

These traits appear to be governed by additive gene action, making them suitable targets for selection in breeding programs. The results of this study are consistent with previous findings by Ramanuj et al. (2018) [16]., who also reported high heritability for traits such as grain yield per plant, canopy temperature depression, and fructan content in wheat genotypes. Additionally, Naveen et al. (2014) [17]. and Rajput (2018) [18]. confirmed high heritability and genetic advance for wheat yield-related traits in different genotypes**​.**

**Conclusion**

This study highlights significant genetic variability among wheat genotypes under both normal and heat stress conditions. Traits such as canopy temperature depression, photosynthetic rate, and fructan content exhibited high genetic variation, making them promising targets for breeding heat-tolerant wheat varieties. The higher phenotypic coefficient of variance (PCV) over genotypic coefficient of variance (GCV) across all traits indicates the influence of environmental factors. High heritability coupled with substantial genetic advance in traits like fructan content, grain yield, spikelets per spike, and photosynthetic rate suggests strong additive genetic control, making selection effective for improving thermotolerance and productivity. These findings support breeding strategies aimed at developing climate-resilient wheat varieties with stable yields under diverse environmental conditions.

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