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

**ABSTRACT**

diverse wheat genotypes were evaluated for genetic variability, heritability and genetic advance 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 the highest for canopy temperature depression, grain yield/plant and the lowest for days to anthesis. Heritability (bs) estimates were high for canopy temperature depression (CTD), followed by yield/plant, grain number /spike, and 1000- grain weight and it was the lowest for days to heading and days to anthesis in all environments. The estimates of genetic advance (GA) were the highest for canopy temperature depression followed by, yield/plant, , grain number/ spike and it was the lowest for days to 50% flowering and days to maturity under (normal, late and very late sowning dates in both seasons. 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 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 for any trait is determined by the degree of variability in the gene pool for thistrait. 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. High heritability estimates simplify the selection process by making it easier in identification of superior genotypes[10].

High heritability (broad sense) is accompanied with high genetic advance; it indicates a strong effectof 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 thre sowing dates representing normal and heat stress conditions. The findings is expected to help in breeding and crop improvement programs by 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 stable climate-resilient wheat varieties.

**Materials and Methods**

The experiment was carried out at Post Graduate Institute Farm, Department of Agricultural Botany, Mahatma Phule Krishi Vidyapeeth Rahuri, Dist. Ahmed nagar (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 rows . A total of l traits based observations were made. Further, observations for days to flowering, days to maturity, plant height, spike length, number of spirelets per spike, number of grain per spike, thousand grain weight, yield per plot, and grain yield per plant were recorded in 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**

**Analysis of variance**

**Performance of the studied genotypes**

**Performance of the studied genotypes under the first date in the first season:**

Table (1) results ................

**Performance of the studied genotypes under the second date in the first season:**

Table (2) results ................

**Performance of the studied genotypes under the third date in the first season:**

Table (3) results ................

**Performance of the studied genotypes under the first date in the second season:**

Table (4) results ................

**Performance of the studied genotypes under the second date in the second season:**

Table (5) results ................

**Performance of the studied genotypes under the third date in the second season:**

Table (6) results ................

**Performance of the studied genotypes overall environments:**

New Table(????) results ................

**Table (1): Variability Parameters of twenty wheat genotypes for yield and yield contributing traits in 1st sowing date in the first season**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 |
|  | Ear head 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 “how did you measure it and in which stages” “ can be inserted in material and methods” | **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 “unit” | **1035.94** | 698.71 | 1367.31 | 17.99 | 19.82 | 8.31 | 82.43 | 348.58 | 33.65 |
|  | Dry Matter at 30days “unit” | **0.66** | 0.51 | 0.86 | 15.45 | 15.77 | 3.15 | 96.02 | 0.21 | 31.19 |
|  | Dry Matter at 60days“how did you measure it and in which stages” “ can be inserted in material and methods” | **6.58** | 5.47 | 7.83 | 10.04 | 12.31 | 7.13 | 66.51 | 1.11 | 16.87 |
|  | Dry Matter at 90days“how did you measure it and in which stages” “ can be inserted in material and methods” | **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 “how did you measure it and in which stages” “ can be inserted in material and methods” | **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 “how did you measure it and in which stages” “ can be inserted in material and methods” | **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 “how did you measure it and in which stages” “ can be inserted in material and methods” | **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 “how did you measure it and in which stages” “ can be inserted in material and methods” | **0.01** | 0.01 | 0.01 | 7.37 | 8.77 | 4.76 | 70.53 | 0.00 | 12.75 |
|  | Pollen viability “how did you measure it and in which stages” “ can be inserted in material and methods” | **88.22** | 82.20 | 95.43 | 3.22 | 5.13 | 4.00 | 39.27 | 3.66 | 4.15 |
|  | PSII sensitivity “how did you measure it and in which stages” “ can be inserted in material and methods” | **0.76** | 0.69 | 0.85 | 4.76 | 7.11 | 5.27 | 44.92 | 0.05 | 6.58 |
|  | Photosynthetic rate “how did you measure it and in which stages” “ can be inserted in material and methods” | **15.97** | 9.61 | 23.75 | 25.25 | 28.34 | 12.85 | 79.43 | 7.40 | 46.36 |
|  | Fructan content at pre anthesis stage “how did you measure it ” “ can be inserted in material and methods” | **3.67** | 3.03 | 5.17 | 16.85 | 17.20 | 3.42 | 96.04 | 1.25 | 34.02 |
|  | Fructan content at post anthesis stage “how did you measure it” “ can be inserted in material and methods” | **1.12** | 0.67 | 1.55 | 17.19 | 17.77 | 4.50 | 93.60 | 0.38 | 34.27 |
|  | Reducing sugar at pre anthesis stage stage “how did you measure it” “ can be inserted in material and methods” | **10.16** | 8.37 | 12.34 | 11.03 | 11.47 | 3.15 | 92.44 | 2.22 | 21.85 |
|  | Reducing sugar at post anthesis stage stage “how did you measure it” “ can be inserted in material and methods” | **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 stage “how did you measure it” “ can be inserted in material and methods” | **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 stage “how did you measure it” “ can be inserted in material and methods” | **0.50** | 0.25 | 0.85 | 31.03 | 31.49 | 5.39 | 97.07 | 0.31 | 62.97 |
|  | Total sugar at pre anthesis stage stage “how did you measure it” “ can be inserted in material and methods” | **11.52** | 9.35 | 14.24 | 12.12 | 12.45 | 2.85 | 94.74 | 2.80 | 24.30 |
|  | Total sugar at post anthesis stage stage “how did you measure it” “ can be inserted in material and methods” | **4.21** | 2.68 | 6.42 | 29.08 | 29.86 | 6.77 | 94.85 | 2.45 | 58.34 |
|  | Senescence Rate stage “how did you measure it” “ can be inserted in material and methods” | **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 date in the first season**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 date in the first season**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 date in the second season**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 (5):Variability parameters of twenty wheat genotypes for yield and yield contributing traits in 2nd sowing date in the second season**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 (6):Varvariability of twenty wheat genotypes for yield and yield contributing traits in 3rd sowing date in the second**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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

The estimates of mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and other variability parameters for each sowing date in each season are presented in Tables (1) to Table (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 (1st sowing date), 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 ( 1st and 2nd sowing date)), highest estimates of GCV were recorded for canopy temperature depression (70.86% and 72.20%), photosynthetic rate (33.13% and 32.77%), and fructan content at pre- and post-anthesis stages (25.34% & 28.18% and 28.45% & 21.19), respectively​.

For Rabi season 2022-23, similar trend was observed in the second season, where high GCV values were recorded in the 1st, 2nd, and 3rd sowing date for canopy temperature depression (53.40%, 69.56%, 73.28%), photosynthetic rate (24.25%, 33.17%, 32.50%), and fructan content at pre- and post-anthesis stages (16.27% &19.56%, 21.93% & 29.72%,, 25.83% & 20.39%, respectively​.

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 are in 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 Table (6).

For Rabi season 2021-22, In normal sowing conditions (1st sowing date), 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 (1st and 2nd ), the highest heritability values were observed for canopy temperature depression (94.34% and 93.35%), photosynthetic rate (97.49% and 93.93%), and fructan content at pre- and post-anthesis stages (97.91% & 98.85% and 98.95% & 95.99%), respectively​.

For Rabi season 2022-23, A similar trend was observed in the second season, where high heritability values were recorded in the 1st, 2nd, and3rd sowing date for canopy temperature depression (97.42%, 98.66%, 88.03%), photosynthetic rate (91.79%, 96.52%, 97.00%), and fructan content at pre- and post-anthesis stages (94.54% and 98.32%, 97.11% and 87.52%, 98.18% and 96.33), respectively​.

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) for 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 thermo-tolerance 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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