

**GENETIC ANALYSIS OF RECOMBINANT INBRED LINE
FOR HEAT TOLERANCE AND PRODUCTIVE TRAIT IN
BREAD WHEAT (*Triticum aestivum* L.)**

By

Harpreet Singh
(Registration No. J-17-M-505)

**Thesis submitted to Faculty of Post Graduate Studies in partial
fulfilment of the requirements for the degree of**

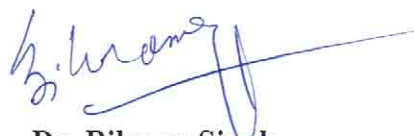
**MASTER OF SCIENCE IN AGRICULTURE
GENETICS AND PLANT BREEDING**



Division of Plant Breeding and Genetics
Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu,
Main Campus, Chatha, Jammu - 180 009
2019

CERTIFICATE-I

This is to certify that thesis entitled "**Genetic Analysis of Recombinant Inbred Line for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)**" submitted in partial fulfillment for the degree of **Master of Science in Agriculture (Genetics and Plant Breeding)** to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agriculture Sciences and Technology of Jammu, is a record of bonafide research work carried out by **Mr. Harpreet Singh**, Registration No. **J-17-M-505** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. The help and assistance received during the course of this investigation have been duly acknowledged.

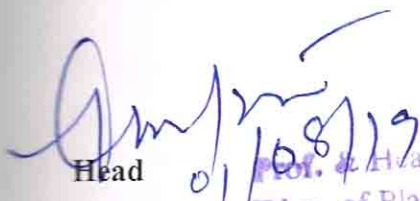


Dr. Bikram Singh
(Major Advisor)

PLACE: Jammu

Date: 01-08-2019

Endorsed



Head

Division of Plant Breeding and Genetics

SKUAST-J, Chatha

Prof. & Head
Division of Plant Breeding & Genetics
SKUAST-J, Chatha-180 009

CERTIFICATE-II

We the members of Advisory Committee of **Mr. Harpreet Singh**, Registration No. **J-17-M-505**, a candidate for the degree of **Master of Science in Agriculture (Genetics and Plant Breeding)** has gone through the manuscript of the thesis entitled **"Genetic Analysis of Recombinant Inbred Line for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)"** and recommend that it may be submitted by the student in partial fulfilment of the requirement for the degree.



Dr. Bikram Singh
Professor
Major Advisor & Chairman
Advisory Committee

Place: Jammu

Date: 01-08-2019

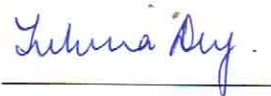
Advisory Committee Members

Member from Major Subject

Dr. Tuhina Dey

Chief Scientist

Division of Plant Breeding & Genetics



Member from Minor Subject

Dr. Ravinder Singh

Assistant Professor,
School of Biotechnology



Dean's Nominee

Dr. B. C. Sharma

Professor/Head
Division of Agronomy

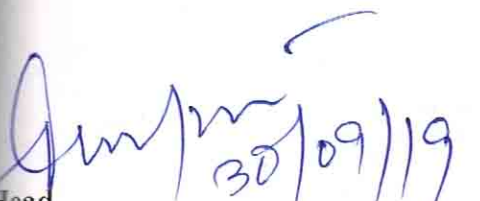


CERTIFICATE – III

This is to certify that the thesis entitled "**Genetic Analysis of Recombinant Inbred Line for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)**" submitted by **Harpreet Singh**, Registration No. **J-17-M-505** to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture (Genetic and Plant Breeding)** was examined and approved by the Advisory Committee and External Examiner(s) on 30.9.19.



External Examiner
(Dr. Pushpindra Rathi)
Ex. Professor, G&PB
GBPUA&T, Pantnagar


Dr. Bikram Singh
Professor
Major Advisor
Head,
Division of Plant Breeding & Genetics

PROF. & HEAD
Divn. of Plant Breeding & Genetics
SKUAST-J, Chatha-180 009


Dean, FoA, SKUAST-Jammu
14/10/2019



Acknowledgements

ACKNOWLEDGEMENT

Before all, I express my heartiest devotion to the almighty, who enriched me each and every moment, whose bounteous love is essence for my life and with whose mercy and blessings, has gifted me with fruitful results and this piece of work being one of them.

I am very thankful for being a part of Sher-e- Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-J, Chatha)

*It is my sublime privilege to express my deep sense of reverence and gratitude to my Advisor **Dr Bikram Singh** Professor, Division of Plant Breeding and Genetics, for his inspiring ingenious guidance, articulate criticism, cordial discussion, unending zeal and constant encouragement which assisted me to overcome every problem that came in my way during the period of this investigation and preparation of this manuscript. I shall always remain indebted to him for his affection and generously bestowed on me and hope he will keep such type of rays of light on me in future.*

*I emphatically extended my heartiest thanks to the worthy members of my advisory committee **Dr. B.C. Sharma**, (Professor and Head, Agronomy), **Dr. Tuhina Dey** (Chief scientist, Division of Plant Breeding and Genetics and **Dr. Ravinder Singh** (Assistant Professor, Division of Plant Biotechnology) for their constant help encouragement and valuable suggestion during the investigation.*

*I greatly acknowledge the help rendered by **Dr. S.K. Gupta** (Professor and Head, Division of Plant Breeding and Genetics) for his mature guidance and ever willing help which led the work to its successful accomplishment.*

*I would be remiss if I don't mention the name of the faculty members **Dr. B.B. Gupta** (Professor), **Dr. Bupesh Kumar** (Assistant professor), **Dr. Parveen Singh** (Assistant professor), **Dr. S.K. Rai** (Assistant professor), Division of Plant Breeding and Genetics and **Dr. M.K. Pandey** (Sr.*

Scientist, Division of Plant Pathology), for their support and cooperation in the division for their support and cooperation.

I am highly thankful to Hon'ble Vice Chancellor **Dr. K.S. Risham** and Dean Faculty of Agriculture, **Dr. D.P. Abrol** for allowing me to undertake the study and for providing necessary facilities to carry out my research work.

I shall always cherish the sweet memories of the living company and sincere cooperation of my loving colleagues, Seniors and Juniors, **Heena Attari, Ruby Sandu, Imran Kohli, Yasir Bhat, Faisal Jameel, Om Parkash, Surbi Kohli, Zaffar Ali, Himani Sharma and Bohemia Singh** for their whole hearted support and constant inspiration during this investigation.

It is with my personal touch and emotions that I seize this opportunity to express my heartfelt and affectionate gratitude to my parents and family members who were always been in my heart and thought. I am gratefully indebted to my beloved godly parents **Sh. Iqbal Singh** and **Smt. Usha Kour**, who always have been an ideal and touch bearer to me. The eternal blessings and love of my elder brother **Mr. Harjinder Singh** and younger brother **Mr. Harminder Singh** inspired me to achieve very best in life. Without their love, graceful sacrifice and constant inspiration this dream would not have materialized.

I am extremely grateful to every single person who has been part of this beautiful journey.

Place : Jammu

Date: 10-10-2019


Harpreet Singh

ABSTRACT

Title of Thesis : **Genetic Analysis of Recombinant Inbred Line for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)**

Name of student : Harpreet Singh

Admission No. : J-17-M-505

Major subject : Genetics and Plant Breeding

Name of Major Advisor : Dr. Bikram Singh, Professor
(Division of Plant Breeding and Genetics)

Degree to be awarded : Master of Science in Genetics and Plant Breeding

Year of award of degree : 2019

Name of University : Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu

ABSTRACT

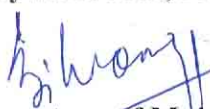
The present study entitled “**Genetic Analysis of Recombinant Inbred Lines for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)**.” was carried out during Rabi 2018-2019 at the experimental area of Division of Plant Breeding and Genetics, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Main Campus, Chatha, with an objective to characterize elite recombinant inbred lines for morpho-physiological traits related to heat and productivity, to study the genetic divergence for heat tolerance in RILs and to study the empirical association of heat traits in determining the grain yield. A set of 30 bread wheat recombinant inbred lines derived from three cross viz. LOK-1 x HUW- 468, LOK 1 x HUW 234 and Raj-4014 x PBN-51, along with two checks namely PBN-51 and HUW-234, were evaluated using a RBD with three replications.

Analysis of variation exhibited significant variation in mean sum square for genotypes in all the traits under study, which revealed sufficient genetic variation present among the RIL population. Grain yield per plant and number of tillers per plant were found to have moderate heritability with low PCV and GCV.

Correlation studies suggested that number of tillers per plant, plant height and chlorophyll content was positively significantly correlated with grain yield per plant at genotypic level. Path coefficient analysis suggested that chlorophyll content, tillers per plant showed significantly positive correlation with grain yield per plant whereas significant negative correlation of relative water loss and canopy temperature with grain yield per plant was observed at genotypic level.

Based on Mahalanobis D^2 analysis, thirty two genotypes were grouped into six clusters. The maximum inter cluster distance was observed between genotype of the cluster II and VI exhibiting maximum divergence. The trait viz. number of days to flowering, relative water content, flag leaf area, number of days to maturity, chlorophyll content and grain yield contributed more than 70% towards divergence.

Keyword: RILs, PCV, GCV, Correlation, Mahalanobis D^2 , Path coefficient,


Signature of Major Advisor


Signature of Student

CONTENTS

CHAPTER	TOPIC	PAGE NO.
I.	INTRODUCTION	1-4
II.	REVIEW OF LITERATURE	5-19
III.	MATERIALS AND METHODS	20-30
IV.	RESULTS	31-48
V.	DISCUSSION	49-57
VI.	SUMMARY AND CONCLUSIONS	58-61
	REFERENCES	62-77
	APPENDICES	I

LIST OF TABLES

Table No.	Description	After Page No.
1	Wheat genotypes used for the evaluation of genetic diversity and heat tolerance studies.	20
2	Analysis of variance based on this mathematical model led to the following breakup of the variance components for all the traits under study.	24
3	Mean sum of squares obtained from analysis of variance for thirteen traits in thirty two wheat genotype.	31
4	Mean performance of thirty two wheat genotype for various physio-morphological characters.	31
5	Estimation of mean, range, phenotypic and genotypic coefficient of variation, heritability and genetic advance for various traits in thirty two wheat genotype under study.	31
6	Genotypic correlations coefficient among thirteen characters for thirty two genotypes of wheat.	35
7	Phenotypic correlations coefficients among thirteen characters for thirty two genotypes of wheat.	37
8	Genotypic path showing direct (diagonal) and indirect (off diagonal) effect of twelve characters on grain yield for thirty two wheat genotype at phenotypic level.	39
9	Phenotypic path showing direct (diagonal) and indirect (off diagonal) effect of twelve characters on grain yield for thirty two wheat genotype at phenotypic level	41
10	Distribution pattern of thirty two genotypes of wheat in various clusters (I-VI) for various heat related traits.	45
11	Inter and intra (diagonal) cluster average of D^2 among different clusters in wheat to study genetic divergence among various Recombinant inbred lines.	45
12	Cluster mean values of different clusters for various characters of thirty two wheat genotype	45
13	Percent contribution towards variability of each character for 32 wheat genotype for various heat related traits.	45
14	Top ranking five RILs for chlorophyll content, canopy temperature and grain per plant.	50

LIST OF FIGURES

Fig. No.	Description	After Page No.
1	Genotypic Path diagram of yield component effects on grain yield in wheat for thirty two wheat genotypes	39
2	Phenotypic Path diagram of yield component effect on grain yield in wheat for thirty two wheat genotypes.	41
3	. Euclidean distance representing average intra and inter cluster.	45

Chapter-1

Introduction

CHAPTER-I

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a self-pollinating annual plant, belonging to the family poaceae. It is a hexaploid (AABBDD) with chromosome number of 42 ($2n=6x=42$) and a genome size of 16 GB. The protein found in wheat is called gluten which renders wheat a multipurpose crop and is a primary protein source for world's inhabitants. Wheat is the major staple food crop and a major source of energy for Indian population. Globally, wheat production stands at 765.5 million metric tonnes with an area of 220.5 million hectares and productivity of 3.4 metric tonnes per hectare (Anonymous 2019a). India produced 101.20 million metric tonnes of wheat during 2018-2019 occupying second place in wheat production after China. It was grown over an area of 29.55 million hectares with average productivity of 3242 kg/ha. (Anonymous 2019b). In Jammu and Kashmir it is grown over an area of 288 thousand hectare, with total production of 504 thousand tonnes and productivity of 17.5 q/ha (Anonymous 2019c). The majority of improvement in productivity has been made in assured irrigated conditions by development of input responsive cultivars. Marginal increase in area under wheat is unlikely to achieve the target. There is no option but to increase yield potential of cultivars grown under various stress conditions.

Majority of the south Asia's rice-wheat zones are coming under heat stressed environment as defined by Fischer and Reynolds. (1996) with mean daily temperature above 17.5°C in the coolest month. In India, rice-wheat system is spread over 11 million hectares in Indo-Gangetic Plains and is responsible for national food security. Wheat crop in this region is exposed to high temperature during grain filling stage (Tandon, 1994; Rane *et al.*, 2000). The North Western Plains are highly productive but more prone to high temperature stress caused by unpredictable north westerly winds but on the other hand wheat grown in North Eastern Plains is exposed to high temperature coupled with high humidity (Joshi *et al.*, 2007). It is already known that heat stress significantly leads to reduction in production and deterioration in the quality of wheat crop. Wheat is very sensitive to high temperature and trends in increasing growing season temperatures have

already been reported for the major wheat-producing regions (Alexander *et al.*, 2006; Hennessy *et al.*, 2008). The average global temperature is reported to be increasing at a rate of 0.18°C every decade (Hansen *et al.*, 2012). Future climates will also lead to greater variability in temperature and increased frequency of hot days (Pittock *et al.*, 2003). To adapt new crop varieties to the future climate, we need to understand how crops respond to elevated temperatures and how tolerance to heat can be improved (Halford *et al.*, 2009).

Heat stress is one of the major causes of yield loss especially at the reproductive and early grain filling stages and numbers and duration of heat events are projected to increase in the future. As there is change in ambient temperature, due to this there is disturbance in metabolism, which results in activation of heat shock proteins, until new cellular equilibriums are reached. Temperature above the optimum for growth can be deleterious, causing injury or irreversible damage, which is called heat stress. Wheat heat stress is more harmful during reproductive phase due to direct effect on grain number and dry weight. Terminal heat stress is likely to increase for wheat in near future. Most of the traits related to yield and heat tolerance are controlled by several genes each with minor effect individually but significant when acting together. The potential trait for screening wheat for heat tolerance includes depression of canopy temperature, flag-leaf, stomatal conductance and photosynthetic rate (Farooq *et al.*, 2011). All these traits are highly correlated with field performance and grain yield under heat stress.

Heat stress affects the metabolic pathways at every stage of growth in wheat, the effect of high temperature is mainly during grain filling and these losses may be up to 40% under severe stress (Wollenweber *et al.*, 2003). High temperatures also leads to decrease in grain weight, early senescence, shriveled grains, reduced starch accumulation, and altered starch-lipid composition in grains, lower seed germination and loss of vigour (Balla *et al.*, 2012). Thylakoid membranes and PS II are considered the most heat-labile cell components. Thylakoid membranes under high temperature show enlargement increased leakiness, physical separation of the chlorophyll light harvesting complex II from the PS II core complex, and disruption of PS II-mediated electron transfer (Ristic *et al.*, 2008). Starch increase in wheat grains can be concentrated by over 30% at temperatures between

30 °C and 40 °C (Stone *et al.*, 1996). Thus, the ability to synthesize, store and remobilize starch at high temperature is crucial to determination of grain sink strength.

Heat stress is currently a major restriction to wheat (*Triticum aestivum* L.) productivity in arid, semiarid, tropical, and subtropical regions of the world (Fischer *et al.*, 1986). It has showed a loss of 3-4% in yield per °C above the optimum day time temperature of 15- 20°C (Wardlaw *et al.*, 1989). This is due to the heat stress that cause an array of physiological, biochemical and morphological changes in wheat (Wahid *et al.*, 2007). There is reduction in the duration of grain growth in response to heat stress during the grain filling stage and it imposed a major limitation for grain yield (Gibson and Paulsen., 1999).

Development in breeding for heat stress for increasing yield potential is more likely to occur if specific characteristics are targeted as it has occurred in grain quality improvement, drought tolerance and disease resistance breeding. Improvement in yield potential requires an understanding of the physiological processes that may be genetically modified to improve the yield. A manifestation for evaluating heat stress is a major requirement for breeding heat tolerant varieties. Stable yield performance of genotypes under heat stress conditions is important to recognize heat tolerant genotypes.

Recombinant inbred lines (RILs) are formed by crossing two inbred lines or purelines followed by successive selfing for sufficient number of generation to create new inbred lines or purelines whose genome is a mosaic of parental genome. The number of RILs obtained from cross of two inbred has a number of advantage for genetic mapping as each RIL needs genotyping only once. Number of individual from each RIL can be used for phenotyping to reduce individual, environmental and measurement of variability. Multiple invasive phenotypes can be obtained on same set of genomes and as the breakpoint in RILs are more dense than those that occur in only one meiosis, greater mapping resolution can be achieved.

The pace of development of heat tolerant varieties is slow, mainly due to non availability of germplasm of divergent forms. Beside, the knowledge about the basic genetic information on heat tolerance is very low, Knowledge of genotype and phenotype

component of variance helps in measuring genetic diversity with nature of variation. Nature of extent of association among such trait help in identification of effective trait to be used as indirect selection parameter to improve economic traits. The above information together with direct and indirect effect helps in formation of correct breeding programme. Although many tolerant cultivar have been identified earlier in wheat germplasm (Reynolds *et al.*, 2001), the characterization of recombinant inbred lines for heat tolerance was undertaken with following objectives:

- To characterize elite recombinant inbred lines for morpho-physiological traits related to heat and productivity.
- To study the genetic divergence for heat tolerance in recombinant inbred line populations.
- To study the empirical association of heat traits in determining the grain yield.

Chapter-2

Review of Literature

REVIEW OF LITERATURE

Wheat (*Triticum aestivum* L.) is the main staple food crop for a large number of world populations. It is the second main, cereal in India after rice. India had a remarkable success during green revolution in wheat production and could increase productivity to the extent that it could bring itself out from insufficiency to a self-sufficient status. Wheat will continue to attract substantial research attentions in the face of the challenge of feeding a predictable global population of 9.8 billion in India by 2050. Yield increases are essential to meet this demand, as expanding the wheat area is not possible (Rajaram and Braun, 2008). In order to meet growing human needs; wheat grain production must increase at an annual rate of 2% (Gill *et al.*, 2004).

HEAT STRESS

Heat stress is a most important environmental factor that substantially reduces wheat grain yield globally especially in arid, semi-arid, tropical, and sub-tropical regions that are related with higher temperature (Wahid *et al.*, 2007). Global warming as a result of climate change negatively affects wheat grain yield, which potentially increases food insecurity and poverty (Ortiz *et al.*, 2008). Annual yield loss in wheat due to global warming is expected to be 7.7 billion dollars, and by 2025, this would be around 18 billion dollars. Stress due to high-temperature has emerged as a most important constraint for the successful wheat production worldwide. Stress due to high-temperature has emerged as a major restriction for the successful wheat production worldwide (Hays *et al.*, 2007).

1. Heat tolerance
2. Genetic divergence studies
3. Morpho-physiological traits related to heat and productivity
4. Character association

HEAT TOLERANCE

Shanahan *et al.* (1990) concluded that high temperature stress during the grain-filling period is a major restraint to increased productivity of spring wheat. Based on membrane thermostability values, 4 genotypes were grouped as heat tolerant and 4 as heat sensitive. The heat tolerant and heat sensitive genotypes produced similar grain yields at two locations but the heat tolerant group produced 21% more grain than the heat susceptible, which was significantly warmer during the grain filling period than the other two locations.

Fisher *et al.* (1991) observed that wheat, initially evolved as a temperate cereal and is now grown in the places with sub-tropical and tropical climate with losses in grain yield due to exposure to heat stress (moderate 15-32°C, high > 32°C) during germination and post-anthesis phase with mean daily temperatures greater than 17.5 °C in coolest months.

Reynolds *et al.* (1997) identified high leaf chlorophyll content in Mexican landrace collections wherein the best genotypes showed substantially greater leaf chlorophyll than the check. High chlorophyll was related with heat tolerance of sister lines in some wheat crosses. The difference in maximum temperatures was 4°C, while the minimum temperature increased by 3°C. Yields were lower than expected (2.3 t/ha). This reduction in yields may be attributed to high temperatures during growing season.

Batts *et al.* (1998) conducted experiment under high temperature field experiments and concluded that root growth was observed to be reduced due to a reduction in the carbon partitioned below ground, and the number and diameter of roots are especially affected if the heat occurs during the reproductive stage. They further observed that warming reduced root dry mass at anthesis while it increased at elevated CO₂ level in coolest and warmest regime, respectively.

Royo *et al.* (2000) stated that the later stages of cell division and enlargement in the grain occur after anthesis and appear to be predominantly sensitive to high temperature. Hence any increase in temperature during that period will result in loss to yield.

Sarkar *et al.* (2001) remarked that early maturing genotypes showed better performance under high temperature stress conditions with less reduction in grain yield, and had relatively higher grain growth rates with more tolerance to heat stress for most of the yield attributing characters. Grain growth rate and heat susceptibility index could be taken as important criteria for breeding genotypes acclimatized to late planting conditions.

Patil *et al.* (2003) conducted an experiment on six early wheat cultivars, namely AKW1071, AKW381, AKW3294, AKW34, HI977 and HD2501 and five sowing dates, i.e. November 15, December 1, December 15, January 1 and January 15 in Akola, Maharashtra. The total biomass at maturity, grains per spike and yield per meter square area was reduced significantly with delay in sowing, as it showed tolerance to high temperature during grain growth phase.

Prakash *et al.* (2003) concluded that in case of lines showing high temperature tolerance observed for grain growth in wheat cultivar HD 2285 is due to its ability to sustain higher activity and catalytic efficiency of soluble starch synthase (SSS) in the developing grains at elevated temperature and higher content of heat shock protein (HSP 100) than susceptible type. Reduced level in SSS activity was observed when excised grains were exposed to gradual rise in temperature from 15°C to 45°C as compared to direct exposure to 45°C. Pre-exposure of excised grains to different temperatures had no significant effect on GBSS activity.

Sharma *et al.* (2006) concluded that in wheat, pre-anthesis phenological phases which determine potential yield components are quite sensitive to high temperature. Pre-anthesis phenology of HD 2285 seemed to be more susceptible than HD 2329 to increase in temperature resulting in increased overall susceptibility. This was also found true for greater susceptibility of pre-anthesis photosynthesis in four cultivar under moderately high temperature.

Farooq *et al.* (2011) observed that heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts, with reductions in dry matter accumulation and grain yield. Genotypes expressing heat shock proteins are better able to withstand heat stress as they protect proteins from heat-induced damage. Heat

tolerance can be enhanced by selecting and developing wheat genotypes with heat resistance. Wheat pre-breeding and breeding should be based on secondary traits like membrane stability, photosynthetic rate and grain weight under heat stress.

Modarresi *et al.* (2011) studied thermo tolerant wheat genotypes under normal and heat stress (late sowing) conditions. Correlations between indices based on grain filling duration and peduncle length had the same direction with yield showing importance and effectiveness of these two traits and their indices for detection and screening of high yielding and thermo tolerant genotypes under normal and stress condition.

Bandana *et al.* (2018) reported that chlorophyll content in wheat lines showed genetic variability significantly under heat stress condition. High reduction in chlorophyll content was recorded in, NWL-12-4(20.21%), NWL-10-14(19.38%), NWL-12-2 (18.58%) and low in, KO-307(12.72%), NWL-12-13(14.92%) in late over normal sown condition. Heat stress at reproductive stage altered the chlorophyll content due to enhance senescence activity. High Chlorophyll and stay green at reproductive stage is an indication of heat tolerance. Heat tolerant wheat genotypes maintain stay green due production high antioxidant enzymes and less chlorophyll activity. The total chlorophyll content (SPAD unit) significantly varied among wheat genotypes under normal, late and very late sown condition at anthesis.

GENETIC DIVERGENCE

Uddin *et al.* (1997) observed highest genotypic coefficients of variation for grains per spike followed by 1000 grain weight, grain yield per plant and spikes per plant. Days to heading, 1000 grain weight and days to maturity exhibited high broad sense heritability. The heritability value was moderate for grains per spike and less for the rest of the characters Genetic advance in percentage of mean was high for 1000 grain weight, grains per spike, days to heading, grain yield per plant and plant height.

Moyghaddam *et al.* (1998) studied genetic variation for agronomic traits in landraces of bread wheat and found highly significant differences among the genotypes for the traits considered. They observed genetic coefficient of variation was relatively low for the developmental characters and plant height in the modern cultivars, the landrace

genotypes were, on average, taller and produced more spikes per plant and had lower values for number of grains per spike, grain yield per plant, and harvest index.

Chen-Xiyong *et al.* (2000) observed that under diverse heat stress treatments, yields and their constituents were significantly reduced, while RILs are significantly different in response to heat stress. Correlation of yield traits with heat tolerance suggested that there were no associations between expressions of agronomic traits with heat tolerance under non-stress conditions, however, significant difference of response of same genotype to heat stress were observed in different heat stress treatments. Combination of both heat susceptibility index and grain weight per spike was suggested as selection criteria for the evaluation of heat tolerance.

Sandeep *et al.* (2000) observed that sowing dates had significant influence on membrane thermostability, specific leaf weight, flag leaf area, chlorophyll content, canopy temperature depression and grain and biological yields. Membrane thermostability and specific leaf weight both were recorded at anthesis and showed negative and positive correlation respectively, with both grain or biomass yields. Canopy temperature depression, flag leaf and chlorophyll did not show significant association with grain or biological yield.

Shukla *et al.* (2001) screened the high temperature and moisture stress tolerance attributes in wheat. They observed high genotypic coefficient of variations for vigour index in plants, tillers per plant, seedling mortality, vigour index, ear length, spike density, grain yield per plant and harvest index. High heritability and genetic advance were observed in, seedling dry weight, vigour index, days to 50% flowering, ear head emergence, ear length and spike density (first sowing), coleoptile length, root length, shoot root ratio, ear length and spike density (second sowing); and, ear length and spike density (third sowing)

Jeena *et al.* (2004) distributed the 40 elite lines of wheat and 5 control cultivars into four clusters. Cluster I and II were further divided into 2 sub-clusters. The majority of the genotypes showing higher yield compared to the best control cultivar for this trait (Raj 3777) belonged to cluster III. The genotypes in cluster II generally showed high values for grains per spike and tillers per m². The cultivar RWP 9910 was superior among the others

for grain per spike. Donors for grain yield included genotypes in cluster III and II B, while donors for earliness included those in cluster IB.

Mohammadi *et al.* (2004) analyzed the recombinant inbred lines (RILs) of wheat derived from the cross between Kauz and MTRWA116. They found the significant difference among RILs for all of the traits under stress and control conditions. Heat shock reduced grain filling duration, kernel weight under heat stress of the RILs, but did not change the number of kernels. The highest correlation was observed between kernel weight and thousand grain weight and the lowest correlation was observed between kernel weight and grain filling duration. It was concluded that kernel weight and kernel weight reduction are the best measurements of heat tolerance and these traits can be used for studies such as quantitative trait loci mapping.

Singh *et al.* (2006) observed that the dates of sowing showed significant differences on all the characters except number of spikelets per panicle. They demonstrated that with the increase in temperature during grain filling period, all the yield components were reduced in mean values ranging from 4.77 to 10.05%. All the yield attributing characters depicted non-significant correlation with average maximum and minimum temperature during grain filling period in the first date of sowing. In the second date of sowing, all the characters showed significantly negative correlation with the maximum temperature. Whereas, all the characters, except number of spikelets per panicle showed considerable negative correlation with the maximum temperature in the third date of sowing with the increase in temperature.

Kumar *et al.* (2009) studied thirty genotypes of bread wheat (*Triticum aestivum* L.) and evaluated for yield and other related characters. Six characters namely plant height, tillers per plant, grain yield, spike length, grains per spike and 1000 grain weight exhibited increase in variability. The remaining traits shows moderate to low variability. Following the Mahalanobis D^2 analysis, all the thirty genotypes were grouped into six clusters. Cluster means suggested that contribution of plant height was the maximum towards genetic divergence followed by days to flowering, grains per spike, 1000 grain weight and days to maturity. Further on the basis of D^2 analysis he suggested that hybridization between genotypes of divergent cluster will lead to accumulation of favourable genes in a single

variety and also suggested to create variability for developing the varieties involving a large number of different lines instead of closely related ones.

Singh *et al.* (2016) carried out field experiment with 109 diverse indigenous genotypes of bread wheat for genetic variability, character association and divergence analysis. Each block had 15 plots of test entries along with 3 checks (*viz.* LOK-1, HD-2009 and WH-147). Different cluster distance was studied. The above discussion clearly shows wide variation from one cluster to another in respect of cluster means for 11 characters, indicating that genotypes having distinctly different mean performance for various characters were separated into different clusters. The crossing between the entries belonging to cluster pairs having large inter-cluster distances and possessing high cluster means for one or other characters to be improved may be recommended for isolating desirable recombinants in the segregating generations in wheat to enhance the production and productivity of this crop in Northern Eastern Plain Zone.

Shahidullah *et al.* (2017) conducted an experiment on 108 bread wheat genotypes to evaluate the genetic diversity for yield and yield contributing parameters under heat stress conditions. The inter cluster distances were higher than the intra-cluster distance, indicating broader genetic diversity among the genotypes of different groups. Increase in value for genetic coefficient of variability are shown for spike weight, number of grains per spike, grain yield per plant, biological yield per plant and canopy temperature depression under heat stress condition. High estimate of heritability acquired for all the traits with the exception of harvest index. In the current study increase in heritability estimate coupled with high genetic advance was seen for plant height, grain per spike, and membrane stability. In their study the highest contribution in expression of genetic divergence was exhibited by chlorophyll content followed by membrane stability, whereas harvest index showed the minimum per cent contribution character toward genetic divergence.

MORPHO-PHYSIOLOGICAL TRAITS RELATED TO HEAT AND PRODUCTIVITY

Palwal *et al.* (1994) studied relationships and genotypic variability among single-leaf photosynthesis, thylakoid activity, and productivity during high-temperature stress at

vegetative and reproductive stages. They studied ten genotypes from major world wheat-producing regions grown under moderate and high temperature. High temperature lowered mean photosynthetic rates by 11%, and mean total biomass by 15% in seedling and maturing plants, respectively. The regime also reduced mean kernel weight by 20% and mean grain yield by 23% relative to the moderate temperature. Lowered photosynthetic rates and diminished productivity of plants were significantly correlated at both growth stages. Relative grain yields were strongly influenced by decreased duration of photosynthetic activity, which ranged widely in the 10 genotypes. Thylakoid stability to heating varied similarly as whole-plant responses to high temperature at seedlings, but not at maturing stage. Genotypes that were most tolerant to high temperature had stable rates and longer durations of photosynthetic activity, high kernel weights, and high harvest indices, which are potential selection criteria.

Stone *et al.* (1996) studied the impact of high temperature evaluated in open field and pot experiments by imposing different temperature regimes during grain filling. Viscoelastic property and protein composition was studied. Agronomic trials indicated that high quality wheat can be obtained in a wide range of growing conditions. Viscoelastic properties were significantly affected by the temperature treatments. High temperatures in wheat seemed to affect mainly the composition of the polymeric fraction (soluble/insoluble polymers) without influencing their synthesis.

Blum *et al.* (2001) suggested that relation between cellular membrane thermostability (CMS) and yield under heat stress were practically significant but not perfect. Other factors besides cellular thermostability may support yield under heat stress. CMS alone cannot be used as the selection criterion for heat tolerance in wheat breeding. It may be used as a additional criterion in the final breeding stages or as a rough selection tool to decrease a large population into the most likely heat tolerant at the early stages of the breeding programme.

Sikder *et al.* (2001) suggested that grain number per ear, 1000 grain weight and main shoot weight of tolerant and moderately tolerant cultivars were higher in comparison to sensitive cultivars, but the relative ear number per plant and relative grain yield of these moderately tolerant and tolerant cultivars ranged from low to high. Tolerant and sensitive

cultivars sown late show lower grain yield than those sown during the optimum sowing date and stated that relative grain number per ear, 1000 grain weight and main shoot grain weight can be used to determine heat tolerance of wheat cultivars under late sowing conditions.

Zahedi *et al.*, (2003) studied growth at 20/15 °C (day/night), exposure of wheat. Plants to moderately high temperature at 30/25 °C which significantly decreased grain weight by decreasing the duration of grain filling, combined with small positive increases in the rate of grain filling. Genotypic variation in response to temperature was also observed for both rate and duration of grain filling, but the variation for the duration, of grain filling among cultivars was small at the higher temperature. Significant correlation was found between single grain weights, but not with the duration, of grain filling at high temperature, which indicated an essential role for synthetic processes concerned in grain filling in the temperature sensitivity of wheat cultivars.

Munjal *et al.* (2004) concluded that the grain weight as possible selection criterion for improving wheat yield. Every 1°C rise in temperature above 15-20°C causes 1.5mg/day reduction in grain weight. He further suggested that along with increasing heat stress intensity, a considerable decrease was observed in yield and yield related traits in all varieties of wheat.

Singh *et al.* (2005) conducted a field experiment to study the physiological traits associated with terminal temperature tolerance under late sowing in irrigated wheat. Results showed that a significant differential genotypic variation for physiological traits. With respect to grain yield and under high post-anthesis temperature, genotypes Halna, K8962, GW173, HD2189, HD2402 and AKW381 showed earliness in their flowering, higher canopy temperature depression (CTD), low membrane thermostability index (MTI), thereby showed a greater degree of high temperature tolerance as compared to long duration wheat genotypes.

Balota *et al.* (2007) used canopy temperature depression to estimate crop yield and to rank genotypes for tolerance to heat and drought with the objectives to evaluate the suitability of CTD for the Texas High Plains environment and to establish optimal

measurement times in relation to growth stage. Under dryland condition, long-term mean CTD at noon and yield were correlated in 2000 and 2001. They observed that the relationship of short-term CTD readings to grain yield was highly variable. Genotype effects on CTD were detected for all hours of day and night. Genotype x hour interaction was insignificant at night, suggesting that night time measurements may provide more stable conditions for CTD comparison among genotypes.

Ali *et al.* (2008) evaluated seventy local and exotic wheat genotypes were evaluated for variability parameters, correlations and path coefficients for eight metric traits i.e., plant height, number of productive tillers per plant, number of spikelets per spike, spike length, number of grains per spike, 1000 grain weight and yield per plant. The evaluation of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were high for yield per plant, number of productive tillers per plant and number of grains per spike. The remaining traits showed moderate to low PCV and GCV estimates. High heritability were recorded for plant height, number of spikelets per spike, spike length, number of grains per spike, 1000 grain weight and yield per plant. Grain yield per plant showed highly significant positive correlation with number of tillers per plant, number of grains per spike and positive correlation with spike length.

Balota *et al.* (2018) conducted research on morphological and physiological traits associated with canopy temperature depression in three closely related wheat lines and they observed that one or more of several physiological characters contributed to constant CTD differences among three closely-related winter wheat genotypes grown under dryland conditions. For three years they measured several leaf traits, including CTD, leaf dimension, gas exchange rates, and carbon-13 isotope discrimination. Data showed that daytime CTD was related to the leaf size in these wheat lines. They concluded that the smaller- and thicker-leaved line had higher grain yield than the large-leaved. Smaller leaves also lead to greater CTD during the day.

Prasad *et al.* (2011) reported that heat stress has significant negative effect on the leaf chlorophyll content however, the reduction is time dependent. While high temperature reduced the chlorophyll content beyond 12 days, drought showed a marginally delayed

effect with a reduction in chlorophyll by 16 and 10 days under combined effect of both heat and drought stress.

Zarei *et al.* (2013) demonstrated that chlorophyll content, grain filling rate and thousand grain weight were associated with both terminal drought and heat stress tolerance. They concluded that under both terminal drought and heat stress conditions, these traits could be more focused in wheat breeding programs. Results of slicing of genotype x environmental interaction showed grain yield reduction of durum cultivars were not significant under terminal drought stress as compared to bread wheat genotype. All wheat genotypes showed significant grain yield reduction under terminal heat stress condition, high yielding genotypes under non-stressed condition showed significant grain yield reduction, when subjected to a stressed condition consequently based on stress susceptibility index these genotypes were not classified into tolerant group.

Kumar *et al.* (2013) concluded that wheat line affected by high temperature at anthesis and later stages showed reduction in biomass, grain filling duration and thousand grain weight but this reduction is dependent on stay green ability of wheat plant.

Gupta *et al.* (2014) studied the effects of water stress on physiological attributes of heat sensitive (Kalyansona) and heat tolerant PBN-51) wheat cultivars in a pot experiment. They demonstrated that correlation coefficient of grain and biological yield with water potential and its components was positive and highly significant. Similarly, turgor potential was also correlated positively and significantly with grain yield at both the stages, but with biological yield it was significant only at the anthesis stage. A negative significant correlation was obtained for diffusive resistance and leaf-to-air temperature gradient with grain yield at the boot and anthesis stages. The rate of transpiration was also positively and significantly correlated to grain and biological yields at both the stages. Amongst the yield attributes, numbers of tillers were positively correlated at the anthesis stage, whereas leaf area and shoot dry weight were significantly correlated with grain and biological yields at both the stages.

Pandey *et al.* (2015) conducted field experiments for evaluating heat tolerance related physiological trait using recombinant inbred lines (RILs) from the cross

RAJ4014/WH730. Pooled analysis showed that CFL (chlorophyll fluorescence) and Chl (chlorophyll content) differed significantly under timely and late sown conditions. The correlation between thousand grain weight with Chl and CFL and correlation between grain wt./spike with Chl and CFL showed that tolerance to terminal heat stress as manifested by low heat susceptibility index. These results suggest that these physiological traits may be used as a secondary character for screening heat-tolerant genotypes.

Rahman *et al.* (2016) concluded that traits such as early ground coverage had positive correlation and had an indirect effect on grain yield. In addition, early ground coverage, spikes per m² and thousand grain weight had positive correlations with grain yield. Most importantly, as early ground coverage, spikes per m² and TGW can be evaluated quickly as well as easily and hence, it is suggested that more emphasis should be given on the morpho-physiological (phenological and physiological) characters for selecting wheat genotypes with higher grain yield under rainfed condition.

Fahad *et al.* (2017) reported that tolerance to heat stress is a complex process and is controlled by various genes controlling a number of morphological and physiological changes. They concluded that morpho-physiological traits showed a varied response against heat stress environment and also have impact on production of wheat amongst all varieties.

Kaur *et al.* (2017) studied two contrasting wheat (*Triticum aestivum* L.) cultivars WH730 (high temperature tolerant) and UP2565 (high temperature sensitive) for differential response to short periods of combined and individually applied high temperature (HT) and drought (D) stress. The combined effects of high temperature and drought were additive. High temperature increased the degree of water stress and the combined effects of drought and high temperature were more severe than those of each individual treatment. This improves the ability of the plant to recover from stress increasing the grain yield and its stability. Genotypes indicating low excised leaf-water loss under drought or heat stress have better capability to maintain water balance in their leaves seems to be attributable to stress tolerance indicating considerable scope for selection under stress conditions.

Sunita *et al.* (2018) studied chlorophyll content using SPAD and NDVI on recombinant inbred lines (RILs) of bread wheat derived from WH1021 (heat tolerant) and WH711 (heat sensitive) wheat genotypes. RILs were studied for these spectral indices under two sowing dates *i.e.* normal and late sown during 2015-16 and 2016-17. Measurements were made at anthesis and 10 days after anthesis. They observed that heat stress has significant negative effect on the leaf chlorophyll content. Average chlorophyll content and NDVI decreases as the temperature increase. They concluded that high temperature above than optimum has drastic effect on chlorophyll content which is also reflected by normalized difference vegetative index (NDVI). A significant difference was observed in timely sown and late sown at 10 days after anthesis for both spectral indices. The result of this study may prove useful in the selection of physiologically efficient heat tolerant genotypes. Further positive correlation of NDVI with chlorophyll content and photosynthetic rate may be useful trait for developing heat tolerant wheat genotypes.

Krishna *et al.* (2018) studied 20 genotypes of spring wheat (*Triticum aestivum* L.) done on the basis of morpho-physiological parameter including canopy temperature and stay green trait under terminal heat stress. Effect of terminal heat stress was studied by delayed sowing at three different dates viz., normal, late and very late taking 20 genotypes of wheat in randomized block design with three replications. Genotypes showed significant differences in their morpho-physiological traits under different environments. Canopy temperature increased with progress in plant growth as well as with delay in sowing. There was significant reduction in total dry matter production, spike number per unit area, grains per ear grains, per spike and 1000 grain weight with delay in sowing.

CHARACTER ASSOCIATION

Singh *et al.* (2003) concluded positive and significant correlation between effective tillers per plant, biological yield per plant and harvest index with grain yield plant by conducting the experiment to estimate correlation in 50 genotypes of bread wheat. However, days to heading had negative significant correlation with 1000-grain weight.

Arya *et al.* (2005) studied 40 genotypes of wheat at two locations *i.e.* Hisar and Bawal with two dates of sowing. Grain yield was found to be positively correlated with

effective tillers per plant, biological yield per plant, grains per ear. Path analysis concluded that biological yield per plant was the main contributor to grain yield per plant in all the four environment. Hence main importance should be given on biological yield in breeding programme.

Majumder *et al.* (2008) studied twenty spring wheat varieties to find out genetic variability and genetic association for grain yield and its component characters. Genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients in most of the traits. Spikes per plant, grains per spike, spike length, and harvest index were the most important characters which possessed positive association with grain yield per plant.

Anwar *et al.* (2009) concluded that grain yield per plant was positively and significantly correlated with number of tillers per plant and days to maturity at genotypic level but non significantly correlated at phenotypic level. Days to maturity showed positive genotypic correlation with grain yield per plant, and number of tillers per plant and TGW. Days to maturity and tillers per plant had positive direct effect on grain yield per plant also. Therefore, more days to maturity and more tillers per plant would be important selection criteria for improving grain yield per plant in the breeding material studied.

Gulnaz *et al.* (2012) studied correlation coefficient analysis in wheat collections to determine the inter-relationship of different yield component traits. Grain yield per plant had positive and highly significant association with number of spikes per plant, plant height, peduncle length, and extrusion length and 1000-grain weight.

Kumar *et al.* (2012) conducted the correlation between yield and its component traits. Grain yield per square meter showed highly significant positive correlation with biological yield and harvest index at genotypic level. Biological yield showed positive significantly correlation with number of spike per square meter. The path coefficient analysis showed that total chlorophyll content had maximum direct effect on grain yield followed by harvest index, 1000-grain weight, days to flowering, CTD and grains/spike under heat stress environment.

Bhushan *et al.* (2013) studied correlation and path analysis of yield and its contributing traits in 40 wheat genotypes. Grain yield had positive correlation with test weight, biological yield, spikelet's per spike, grain filling period and negative correlation with days to heading, plant height and days to maturity with grain yield.

Nukasani *et al.* (2013) evaluated 114 pre-breeding lines of bread wheat. Correlation and path analysis studies revealed that three characters, tiller number per meter, grain weight per spike and number of grains per spike are the most important as these exhibited positive and strong association and maximum positive direct effect on grain yield.

Khan *et al.* (2014) studied 25 spring wheat genotypes under normal and late sown conditions. Chlorophyll content of flag leaf at anthesis and 21 days after anthesis revealed a negative correlation with canopy temperature and grain filling rate, while a positive correlation was observed with grain filling duration, total biomass, grain filling rate and spikes number per m² with grain yield.

Kyosev and Desheva, (2015) reported a significant and positive correlation of grain yield per plant with plant height, grain weight per spike, number of grains per spike and 1000-grain weights in emmer wheat genotypes. Grain weight per spike and plant height had a direct effect on grain yield.

Bhushal and Sarial, (2016) concluded that chlorophyll content and chlorophyll fluorescence at anthesis and seven days after anthesis had a positive and significant correlation with grain number per spike, grain weight per spike, grain filling rate and grain yield. Canopy temperature was found to show significantly negative association with 1000-grain weight.

Chapter-3

Material and Methods

CHAPTER-III

MATERIAL AND METHODS

The present study entitled “**Genetic analysis of recombinant inbred lines for heat tolerance and productive trait in wheat (*Triticum aestivum* L.)**” was carried out at the Research Farm of Division of Plant Breeding and Genetics, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Main Campus, Chatha, Jammu during *Rabi* 2018-2019.

Sher-e-Kashmir University of Agricultural Science and Technology of Jammu, Chatha is situated at an altitude of 332 m above sea level with 32° 39' degree N latitude and 74° 58' E longitude with an annual rainfall of 1000 mm and, represents sub-tropical conditions.

Experimental Material

The experimental material consist of 450 RILs derived from three crosses involving five genotype namely LOK- 1, HUW- 468 , HUW-234, Raj-4014 and PBN-51 which were grown during *Rabi* 2017-2018 in an augmented design with check after every 20 lines as depicted in table 1.

Table 1: Wheat genotypes used for the evaluation of genetic diversity and heat tolerance.

Cross	Variety	No. of RIL
A	LOK-1 × HUW- 468	150
B	LOK 1 × HUW 234	150
C	Raj-4014 × PBN-51	150

A total of 450 RILs were used and they were evaluated for various morpho-physiological characters. Based on the mean data of 450 lines, 10 RILs from each of the three crosses were selected exhibiting better morpho-physiological character. Total of 30 RIL along with two check namely PBN 51 and HUW 234 were evaluated during *Rabi*

2018-2019 in two rows of five meter using RBD design in three replication for morphological and physiological traits to select elite RILs for heat tolerance and grain yield.

3.2 Recording of observations

Data were recorded on randomly selected five plants from each wheat genotype on the following morphological and physiological traits.

3.2.1 Morphological traits

3.2.1.1 Number of days to fifty per cent flowering:

The number of days from date of sowing to date when fifty percent of plants flowered of in the rows was recorded.

3.2.1.2 Number of days to maturity:

The number of days taken from date of sowing to the full maturity of crop was recorded.

3.2.1.3 Plant height (cm):

Height of the plant in centimetres was recorded from the ground level to the top of the ear (excluding awns) of the main shoot of each plant at the time of maturity.

3.2.1.4 Number of tillers per plant:

At maturity the number of fertile tillers per plant were counted and averaged.

3.2.1.5 Number of grains per ear:

Five ears from each of the five selected plants in each progeny from each replication were taken at maturity stage prior to harvesting. Number of grains of each ear was counted separately after thrashing them manually and the mean data obtained was represented as number of grains per ear for each progeny.

3.2.1.6 Grain yield per plant (g):

The grain yield of five randomly selected plants from each progeny was weighed in grams. Average of five plants was worked out.

3.2.1.7 Thousand grain weight (g):

One thousand grains from each genotype were counted and weighed in grams on electrical balance.

3.2.2 Physiological traits

3.2.2.1 Chlorophyll content

To measure chlorophyll content SPAD meter was used. The SPAD measurements were conducted in the field between 10:00 and 16:00 h. The adaxial side of the leaves was always placed toward the emitting window of the instrument and major veins were avoided. Leaves at different development stages were selected, including premature, fully mature and senescent leaves and chlorophyll content was measured. As procedure described by (Uddling *et al.*, 2007).

3.2.2.2 Flag leaf area (cm²)

Three measurement were taken from each line and leaf area was estimated from leaf length and width measurements by using the equation $A = 0.75 LW$ as described by Aldesuquy *et al.* (2014).

$$A = L \times W \times A$$

L= length of leaf

W= leaf maximum width

A= Constant which has value of the constant (A) is 0.75.

3.2.2.3 Canopy temperature (°C):

Canopy temperature was measured with an infrared thermometer at the grain filling stage as described by Olivares-Villegas *et al.* (2007). Five measurements per plot were taken. Canopy temperature was recorded by a handheld infrared thermometer (IMPAC Electronic GmbH, Germany) on bright sunny days between 1pm and 3 pm at grain filling stage. For each plot five measurements were made at approximately 0.5-1 m distance from the edge of the plot and approximately 50 cm above the canopy with an approximate angle of 30°-60° from horizontal giving a canopy view of 10cm × 25 cm. (Ayenesh *et al.*, 2002).

3.2.2.4 Canopy temperature depression ($^{\circ}\text{C}$):

Canopy temperature depression was calculated using formula as, $\text{CTD} = \text{Ambient temperature} - \text{canopy temperature}$. Ambient temperature was measured after recording observation in each plot, using a handheld thermometer.

3.2.2.5 Relative leaf water content (%):

To measure RWC at grain filling stage, three fresh flag leaves were detached from each plot and weighed immediately to record fresh weight. Fresh leaves were floated in distilled water for 24 hours. Excess water of leaves was wiped-off and weight to record saturated weight, and then oven-dried at 70°C for 48 hours for dried weight measurement. The RWC was computed using the following equation:

$$\text{RWC (\%)} = [(\text{FW}-\text{DW}) / (\text{TW}-\text{DW})] \times 100,$$

Where,

FW – Sample fresh weight

TW – Sample turgid weight

DW – Sample dry weight.

3.2.2.6 Relative water loss (%)

Fresh weight of the excised leaves was measured and leaf samples were spread on laboratory bench for six hour to wilt at room temperature (20°C) .After six hour leaves were weighted again to obtain wilted weight .The leaves were then oven dried for 72 hour at 70°C and dry weight was recorded as described by Rahman *et al.* (2000).

$$\text{RWL (\%)} = \frac{\text{FW}-\text{WW}}{\text{DW}} \times 100$$

FW = Sample fresh weight

WW=Sample Wilted weight

DW=Sample dry weight

3.3 Statistical Analysis

The observations recorded for the various morphological and physiological traits were subjected to the following statistical analysis:

3.3.1 Mean performance

The mean or average of the each of above recorded traits was used to test the performance of the 32 wheat genotypes used in present study.

3.3.2 Analysis of variance

To test the significance of differences among different genotypes used in the study, the data on mean values for different characters was analysed as per standard statistical procedure for randomized block design as proposed by Panse and Sukhatme, 1984. Different biometrical measures that were used to explain dispersion of variability includes:

1. **Range:** It was expressed as the difference between the lowest value and the highest value present in the observation for each trait.
2. **Standard deviation (σ):** Expressed in terms of square root of variance.

$$SD = \sqrt{Var} = \sqrt{\sigma^2} = \sigma$$

3. **Variance:** Expressed as the average of squared deviation of all the individual observation from the mean. Mathematically

$$\text{Variance (var.) or } \sigma^2 = \frac{\sum (x - \bar{x})^2}{N - 1}$$

4. **Standard error (SE):** Expressed as the mean difference between sample estimates of mean and the population parameter μ i.e. it is the measure of uncontrolled variation present in a sample. Mathematically

$$\text{Standard error} = \frac{\text{Standard deviation}}{\sqrt{N}}$$

Where,

N = Total number of observations

In fact, S.E is the SD of means and is expressed as SE_m

5. Coefficient of variation (CV):

$$CV (\%) = \text{Standard deviation} / \text{Mean} \times 100$$

Table 2: Analysis of variance based on this mathematical model led to the following breakup of the variance components for all the traits under study.

Source of variation	d.f	MSS	Expectation of MSS
Replications	(r-1)	M_r	
Genotypes	(g-1)	M_g	$\sigma_e^2 + r\sigma_g^2$
Error	(r-1) (g-1)	M_e	σ_e^2
Total	rg-1		

Where,

r	=	number of replications
g	=	number of genotypes
M_r	=	Mean sum of square due to replications
M_g	=	Mean sum of square due to genotypes
M_e	=	Mean sum of square due to error

The genotypic and phenotypic variances were estimated as suggested by Lush, (1940).

1. Genotypic variance

$$V_g = \frac{M_g \times M_e}{r}$$

2. Phenotypic variance

$$V_P \text{ or } \sigma_p^2 = M_g + M_e$$

1. Phenotypic coefficient of variation (PCV)

The phenotypic and genotypic variance was further used to compute coefficient of variance as suggested by Burton (1952).

$$PCV (\%) = \frac{\sqrt{\text{Phenotypic Variance}}}{\text{Mean}} \times 100$$

$$= \frac{\sqrt{V_p}}{\bar{X}} \text{ or } \frac{\sigma_p}{\bar{X}} \times 100$$

2. Genotypic coefficient of variation (GCV)

$$\begin{aligned} \text{PCV (\%)} &= \frac{\sqrt{\text{Genotypic Variance}}}{\text{Mean}} \times 100 \\ &= \frac{\sqrt{V_g}}{\bar{X}} \text{ or } \frac{\sigma_g}{\bar{X}} \times 100 \end{aligned}$$

Where,

σ_p , and σ_g are phenotypic and genotypic standard deviation respectively.

The PCV and GCV were classified as suggested by Sivasubramanian and Madhavamenon (1973).

Low	:	less than 10%
Moderate	:	10-20%
High	:	More than 20%

3.4.3 Genetic parameters

1. **Heritability (broad sense) h^2_{bs} :** It was calculated by the method adopted by Lush (1940) and expressed as percentage.

$$\begin{aligned} \text{Heritability (broad sense) (\%)} &= \frac{\text{Genotypic Variance}}{\text{Phenotypic Variance}} \times 100 \\ &= \frac{\sigma_g^2}{\sigma_p^2} \end{aligned}$$

As suggested by Johnson *et al.* (1955) heritability values were categorized as follows

Low	:	less than 30%
Moderate	:	30-60%
High	:	More than 60%

2. Genetic advance (GA):

The expected genetic gain or advance under selection was estimated by following method as suggested by Johnson *et al.* (1955)

$$\text{Genetic advance (GA)} = \sigma_p \times h^2 \times k$$

Where,

σ_p = Phenotypic standard deviation of the original population for the character

h^2 = Heritability coefficient

k = Selection differential at particular level of selection intensity, which is 2.06 for 5 per cent selection intensity

$$\text{Genetic advance as percent of means} = \frac{\text{Genetic advance}}{\text{Mean}}$$

Genetic advance as percent of mean was calculated as suggested by Johnson *et al.* (1955)

Low	:	Less than 10%
Moderate	:	10-20%
High	:	More than 20%

3.4.4 Correlation

3.4.4.1 Correlation coefficient:

The correlations between all the characters under study at genotypic and phenotypic levels were estimated according to the method given by Searle (1961) using the following formula:

1. Phenotypic correlation between characters X and Y

$$r_{xy}(p) = \frac{\text{Cov. XY}(p)}{\sqrt{\text{Var. X}(p) \times \text{Var. Y}(p)}}$$

2. Genotypic correlation between characters X and Y

$$r_{xy}(g) = \frac{\text{Cov. XY}(g)}{\sqrt{\text{Var. X}(g) \times \text{Var. Y}(g)}}$$

Where,

Cov. XY (p) and Cov. XY (g) denote phenotypic and genotypic covariance between characters X and Y, respectively. Var X (p) and Var. X (g) denote variance for character X, while Var. Y (p) and Var. Y (g) denote phenotypic and genotypic variance for character Y, respectively.

Test statistics

$$t_c = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}; (n-2) \text{ df.}$$

Path coefficient analysis

Path coefficient analysis was carried out using phenotypic and genotypic correlation values of yield components on yield as suggested by Wright (1921) and illustrated by Dewey and Lu (1959). Standard path coefficients, which are the standardized partial regression coefficients, were calculated. These values were obtained by solving the following set of 'p' simultaneous equation using above package.

$$P_{01} + P_{02} r_{12} + \dots + P_{0p} r_{1p} = r_{01} \quad P_{01} + P_{12} r_{02} + \dots + P_{0p} r_{2p} = r_{02}$$

$$P_{01} + r_{1p} + P_{02} r_{2p} + \dots + P_{0p} = r_{0p}$$

Where,

$P_{01}, P_{02}, \dots, P_{0p}$ are the direct effects of variables 1,2,-----p on the dependent variable 0 and $r_{12}, r_{13}, \dots, r_{1p}, \dots, r_{p(p-1)}$ are the possible correlation coefficients between various independent variables and $r_{01}, r_{02}, r_{03}, \dots, r_{0p}$ are the correlation between dependent and independent variables.

The indirect effects of the i^{th} variable via j^{th} variable is attained as $(P_{0j} \times r_{ij})$. The contribution of remaining unknown factor is measured as the residual factor, which is calculated and given below.

$$P^2_{OX} = 1 - [P^2_{01} + 2P_{01}P_{02}r_{12} + 2P_{01}P_{03}r_{13} + \dots + P^2_{02} + 2P_{02}P_{03}r_{23} + \dots + P^2_{0p}]$$

$$\text{Residual factor} = \sqrt{(P^2_{OX})}$$

3.5 D² analysis

3.5.1 Estimation of D² value

The genetic divergence in 25 genotypes was estimated by Mahalanobis D² statistic (generalized distance as suggested by Rao, 1952). The twelve characters as outlined in this chapter were included for this analysis.

The calculation for D^2 values involved the following steps (Murthy and Arunachalam, 1967).

1. A set of uncorrelated linear combination (Y 's) was obtained by pivotal condensation of the common dispersion matrix (Rao, 1952) of a set of correlated variables (X 's).The common dispersion matrix was arranged with the help of error mean sum of squared and sum of products.
2. Using the relationship between Y 's and X 's the mean value of different characters (X_1 to X_{12}) were transformed into the mean values of a set of uncorrelated combinations (Y_1 to Y_{12}).
3. The D^2 values between i^{th} and j^{th} genotypes for the k^{th} character is calculated as given:

$$D^2_{ij} = \sum_{t=1}^k (Y_{it} - Y_{jt})^2$$

4. The ' k ' component and D^2 for each combination was ranked in descending order of magnitudes.
5. The ranks were added up for each component D^2 over all combinations and the rank total was obtained.

3.5.2 Group constellation

Varieties were grouped into a number of clusters. D^2 being treated as square of generalized distance for diversity analysis.

The criterion used in clustering by this method is that any two genotypes belonging to the same cluster showed, at least on an average, a smaller D^2 value than those belonging to different clusters.

In other words, if varieties V_1 and V_2 are close together and variety V_3 is distant from both of them as shown by this generalized distance, than V_1 and V_2 form one cluster. The average D^2 value of all possible combination of genotypes/ varieties in one cluster with those in other was computed and its square root was used to represent the "Statistical distance" between two clusters.

3.5.3 Contribution of different characters to divergence

The relative contribution of characters to the total D^2 between each pair of genotypes was given a score of 1 to 12 (there are twelve characters) based on the magnitude of D^2 value due to each characters. A rank of 1 represented the highest contribution, 12th the lowest. Percentage contribution of each character was calculated as under:

$$\text{Percentage contribution of X character} = \frac{N(X) \times 100}{n(n-1)/2}$$

Where,

$N(X)$ = Number of genotypic combinations which were ranked for character X out of the total genotypic combinations of $n(n-1)/2$.

$n(n-1)/2$ = Total possible genotypic combination among 'n' number of genotypes.

Chapter-4

Results

RESULT

The present study entitled, “**Genetic analysis of recombinant inbred lines for heat tolerance and productive trait in bread wheat (*Triticum aestivum* L.)**” was undertaken by evaluating thirty recombinant line along with two check namely HUW 234 and PBN 51 varieties of hexaploid wheat to generate information on the genetic divergence and character association to screen heat tolerant recombinant inbred lines during *Rabi* 2018-2019. Observations were recorded on yield and physiological traits related to heat tolerance. The result of the present study is presented under the following heading:

- 4.1 Analysis of variance and components of variation
- 4.2 Genetic variability
- 4.3 Character association
- 4.4 Path coefficient analysis
- 4.5 Genetic Divergence

4.1 Analysis of variance and components of variation

Thirty wheat RILs along with two checks were analyzed in randomized block design with three replication during *Rabi* 2018-19. Analysis of Variance (Table 3) for 13 morphological and physiological traits as a measure of variability indicated mean square for genotypic differences highly significant for all the characters, viz. number of days to flowering, number of days to maturity , plant height (cm), number of tillers per plant, number of grains per ear, thousand grain weight (g), flag leaf area (cm²), chlorophyll content (SPAD unit), relative water content (%), relative water loss (%), canopy temperature (°C) and canopy temperature depression (°C).

The result indicates that there were significant genotypic differences for all the morpho-physiological traits under study. These differences could be used for distinguishing different genotypes from each other.

4.2 Genetic variability for morphological and physiological traits

Data were recorded on 32 genotypes for yield and its various component traits. Mean performance of 32 wheat genotypes for physio-morphological characters is presented in table 4(a) and 4(b). The estimate of general mean, range, genotypic and phenotypic variance, coefficient of variation, heritability and genetic advance is presented in table 5. A wide range of variation was observed for all the thirteen characters under study.

Number of days to fifty percent flowering

Day to fifty percent flowering exhibited significant genotypic difference with RIL 30 of Cross 3 showing least number of day to flowering i.e. 78.41 and RIL 29 of Cross 3 showing maximum days to flowering i.e. 108.66 with an overall mean of 98.29. Phenotypic variance (6.42) recorded was higher than genotypic variance (5.94). Heritability estimate was high (85.9) whereas expected genetic gain as per cent mean was moderate (11.34) for this character.

Number of days to maturity

Mean square due to number of day to maturity exhibited significant genotypic difference with the range varying from 101.00 to 130.87 days with an overall mean of 118.85 days. Earliest maturity was shown by Cross 1 RIL 24 and maximum number of days to maturity was recorded by Cross 2 RIL 12. Phenotypic variance (8.02) was greater than genotypic variance (5.34). Heritability estimate was moderate (44.4) whereas genetic advance as per cent mean was low (7.33) for this character.

Plant height (cm)

Plant height exhibited significant genotypic differences and its range varied from 62.81 for Cross 3 RIL 26 to 116.78 for check 2, i.e PBN-51 with an overall mean of 85.37. The phenotypic variance was higher than genotypic variance i.e. 14.82 and 11.27, respectively. Heritability value and genetic advance as per cent of mean was moderate for this character i.e 57.8 and 17.66, respectively.

Table 3: Mean sum of squares obtained from analysis of variance for 13 traits in 32 wheat genotype

Source of variation	d.f	Mean sum of square							
		Number of days to fifty per cent flowering	Number of days to maturity	Plant Height (cm)	Number of tillers per plant	Number of grains per ear	Thousand Grain weight (g)	Flag leaf area (cm ²)	Grain yield ¹ (g)
Replication	2	148.88	1130.04	12223.32	0.002	153.18	35.41	263.87	1.95
Genotype	31	108.08**	171.61**	346.89**	2.25**	18.74**	39.99**	45.48**	5.23**
Error	62	5.62	5.62	67.83	0.73	5.52	13.48	3.73	1.03

Source of variation	d.f	Mean sum of square				
		Chlorophyll content (SPAD unit)	Relative water content (%)	Relative water loss (%)	Canopy temperature (°C)	Canopy temperature depression (°C)
Replication	2	0.31	1.27	30.37	42.02	0.08
Genotype	31	4.93*	40.68**	18.49**	25.86**	0.79**
Error	62	2.68	2.82	9.66	7.74	0.38

*, ** significantly at 5% and 1% levels, respectively

Table 4(a): Mean performance of 32 wheat genotype for various physio-morphological characters.

S.No	GENOTYPE	DTF	DTM	PH (cm)	TPP	G/E	TGW (g)	FLA (cm ²)
1	CROSS 1 RIL 1	97.59	119.00	96.78	10.35	42.66	37.82	34.45
2	CROSS 1 RIL 2	89.66	126.66	93.43	9.51	39.44	36.81	33.67
3	CROSS 1 RIL 3	93.66	122.33	85.58	9.33	42.33	32.77	33.38
4	CROSS 1 RIL 4	94.66	121.66	99.12	8.77	41.77	33.24	33.84
5	CROSS 1 RIL 5	96.66	124.66	81.27	9.22	40.44	28.72	28.36
6	CROSS 1 RIL 6	97.66	125.66	98.95	9.44	43.89	30.66	30.91
7	CROSS 1 RIL 7	99.66	111.66	85.01	8.56	42.67	29.80	29.98
8	CROSS 1 RIL 8	97.16	109.00	80.03	8.44	39.11	28.14	31.30
9	CROSS 1 RIL 9	104.66	111.33	82.06	9.00	40.66	27.14	22.29
10	CROSS 1 RIL 10	100.66	108.66	86.46	9.88	45.89	27.27	35.70
11	CROSS 2 RIL 11	104.66	123.00	78.99	11.46	41.33	25.82	34.73
12	CROSS 2 RIL 12	98.33	130.87	86.52	9.54	39.22	22.39	35.23
13	CROSS 2 RIL 13	106.00	125.66	88.69	9.78	42.11	24.23	34.18
14	CROSS 2 RIL 14	94.66	127.33	85.98	9.33	40.00	28.71	29.08
15	CROSS 2 RIL 15	103.66	122.33	69.42	9.22	39.78	29.34	31.15
16	CROSS 2 RIL 16	93.16	119.33	80.25	8.89	40.22	27.63	33.76
17	CROSS 2 RIL 17	96.66	127.33	77.09	8.78	43.22	29.78	32.58
18	CROSS 2 RIL 18	95.66	125.66	86.6	8.89	41.00	30.11	31.10
19	CROSS 2 RIL 19	101.66	114.00	87.76	8.22	45.89	30.56	32.75
20	CROSS 2 RIL 20	89.66	123.33	80.13	7.44	38.55	31.15	35.23
21	CROSS 3 RIL 21	104.66	113.66	81.75	8.00	41.77	31.99	32.72
22	CROSS 3 RIL 22	97.66	113.00	92.49	8.67	38.66	32.15	32.41
23	CROSS 3 RIL 23	96.12	109.66	87.41	8.67	40.22	38.06	31.95
24	CROSS 3 RIL 24	95.13	101.00	86.04	8.89	36.11	32.98	21.64
25	CROSS 3 RIL 25	103.66	105.33	71.44	8.56	41.89	36.71	31.72
26	CROSS 3 RIL 26	99.66	119.66	62.81	7.89	41.22	29.95	30.37
27	CROSS 3 RIL 27	92.66	121.00	73.94	8.56	41.22	31.99	36.10
28	CROSS 3 RIL 28	99.66	113.66	79.11	6.67	38.89	30.83	22.16
29	CROSS 3 RIL 29	108.66	128.46	84.5	9.00	39.77	31.55	32.28
30	CROSS 3 RIL 30	78.41	126.84	76.18	8.33	37.77	33.29	25.32
31	Check1 HUW234	101.66	114.00	108.42	10.33	34.15	27.74	36.50
32	Check 2 PBN 51	102.00	117.66	116.78	10.00	37.08	33.81	31.42
	MEAN	98.29	118.85	85.37	9.28	40.59	30.72	31.51
	C.V(%)	2.41	5.98	9.65	11.26	5.80	11.95	6.13
	S.E	1.36	4.10	4.75	0.6	1.35	2.12	1.11

PH-Plant height (cm), G/E-Number of grain per ear, TPP- Number of tillers per plant, FLA-Flag leaf area (cm²), DTM- Number of days to maturity, DTF- Number of days to flowering , TGW-Thousand grain weight (g)

Table 4(b): Mean performance of 32 wheat genotype for various physio-morphological characters

S.No.	GENOTYPE	CC (SPAD Unit)	RWC (%)	RWL (%)	CT (°C)	CTD (°C)	GY ⁻¹ (g)
1	CROSS 1 RIL 1	38.57	63.72	77.58	20.70	8.24	16.20
2	CROSS 1 RIL 2	37.86	57.62	77.26	21.07	7.64	15.12
3	CROSS 1 RIL 3	40.00	58.28	78.48	26.15	7.66	16.81
4	CROSS 1 RIL 4	37.21	63.50	77.99	19.44	7.7	15.99
5	CROSS 1 RIL 5	37.72	60.86	75.21	20.70	7.92	15.47
6	CROSS 1 RIL 6	36.94	52.10	74.92	24.85	7.91	14.41
7	CROSS 1 RIL 7	38.39	58.24	74.13	21.08	7.72	15.64
8	CROSS 1 RIL 8	37.16	50.78	74.69	20.72	7.21	17.75
9	CROSS 1 RIL 9	37.76	56.02	73.00	27.29	5.92	17.35
10	CROSS 1 RIL 10	38.49	53.04	74.72	18.62	7.78	15.91
11	CROSS 2 RIL 11	39.33	56.59	76.58	24.39	7.66	16.21
12	CROSS 2 RIL 12	40.3	55.67	72.92	20.59	8.23	17.59
13	CROSS 2 RIL 13	38.00	58.71	73.16	22.43	7.65	17.57
14	CROSS 2 RIL 14	40.02	60.42	72.13	24.64	7.86	15.78
15	CROSS 2 RIL 15	41.44	53.18	76.40	21.02	7.30	16.42
16	CROSS 2 RIL 16	39.7	60.95	72.46	23.23	7.20	14.46
17	CROSS 2 RIL 17	38.37	58.40	77.26	18.28	7.56	16.12
18	CROSS 2 RIL 18	39.82	50.33	73.67	20.91	7.50	15.40
19	CROSS 2 RIL 19	38.66	54.49	80.86	20.14	6.97	15.17
20	CROSS 2 RIL 20	39.76	59.40	78.23	21.29	7.68	17.73
21	CROSS 3 RIL 21	39.36	54.74	76.62	24.14	7.94	16.27
22	CROSS 3 RIL 22	37.44	56.78	77.37	17.87	7.89	16.93
23	CROSS 3 RIL 23	40.52	59.02	75.80	26.27	7.11	14.82
24	CROSS 3 RIL 24	40.09	54.60	72.86	17.74	7.44	16.50
25	CROSS 3 RIL 25	38.87	54.48	74.10	26.86	7.27	16.76
26	CROSS 3 RIL 26	37.22	53.52	76.36	21.47	7.93	15.46
27	CROSS 3 RIL 27	37.75	57.79	77.09	17.42	7.16	17.65
28	CROSS 3 RIL 28	37.1	56.98	75.63	18.01	8.08	16.53
29	CROSS 3 RIL 29	38.43	63.11	75.34	25.19	7.69	15.32
30	CROSS 3 RIL 30	38.47	50.88	74.74	21.51	7.14	18.07
31	Check1HUW 234	39.42	60.78	76.45	16.83	8.25	19.41
32	Check 2 PBN 51	41.78	59.59	67.52	20.64	6.22	20.15
	MEAN	38.85	57.13	75.36	21.61	7.54	16.47
	C.V(%)	4.27	3.92	4.12	12.87	8.14	6.17
	S.E	0.95	1.29	1.79	1.60	0.35	0.58

CT=Canopy temperature (°C), CTD-Canopy temperature depression (°C), RWC-relative water content (%), CC-Chlorophyll Content (SPAD unit) , RWL-Relative water loss (%), GY⁻¹ Grain yield per plant (g).

Table 5: Estimation of mean, range, phenotypic and genotypic coefficient of variation, heritability and genetic advance for various traits in 32 wheat genotype under study.

Character	Mean	Range	Environmental coefficient of variance (%)	Genotypic coefficient of variance (%)	Phenotypic coefficient of variance (%)	h ² (Broad sense heritability)	Genetic advance	Expected genetic gain (percent of Mean)
Number of days to fifty per cent flowering	98.29	78.41-108.66	2.41	5.94	6.42	85.9	11.15	11.34
Number of days to maturity	118.85	101.00-130.87	5.98	5.34	8.02	44.4	8.71	7.33
Plant height (cm)	85.57	62.81-116.78	9.62	11.27	14.82	57.8	15.10	17.66
Number of tillers per plant	09.28	6.67-11.46	9.54	7.92	12.41	40.8	0.93	10.42
Number of grains per ear	40.59	34.15-45.89	5.80	5.16	7.76	44.3	2.87	7.08
Thousand Grain weight (g)	30.72	22.39-38.06	11.91	9.67	15.37	39.6	3.853	12.54
Flag leaf area (cm ²)	31.51	21.64-36.50	6.13	11.83	13.33	78.8	6.82	21.65
Chlorophyll content (SPAD Unit)	38.85	36.94-41.78	4.21	2.23	4.77	21.9	0.83	2.15
Relative water content (%)	57.13	50.13-63.72	2.94	6.23	6.89	81.7	6.61	11.60
Relative water loss (%)	75.36	67.52-80.86	4.12	2.27	4.72	23.3	1.70	2.26
Canopy temperature (°C)	21.61	16.83-27.29	12.87	11.37	17.18	43.8	3.35	15.50
Canopy temperature depression (°C)	07.54	5.92-8.24	8.17	4.95	9.56	26.9	0.39	5.29
Grain yield ^{±1} (g)	16.47	14.46-20.15	6.17	7.18	9.47	57.5	1.84	11.21

Number of tillers per plant

Tillers per plant showed significant genotypic difference and it ranged from 6.67 for Cross 3 RIL 28 and 11.46 for Cross 2 RIL 11 with general mean of 9.28. The phenotypic variance (12.41) was higher than genotypic variance (7.92). This trait exhibited moderate value for both heritability and expected genetic gain as per cent mean i.e 40.8 and 10.42, respectively.

Number of grains per ear

Number of grains per ear showed significant genotypic difference and it ranged from 34.15 to 45.89 for check 1 i.e. HUW 234 and Cross 2 RIL 19, respectively with the general mean of 40.59. Value of phenotypic variance was greater than genotypic variance, having values 7.76 and 5.16, respectively. Heritability estimate showed moderate value (44.3) whereas genetic advance as per cent mean showed lower value (7.08).

Thousand grain weight (g)

Thousand grain weight showed significant genotypic difference with lowest and high value 22.39 and 38.06, respectively with the overall mean of 30.72. Lowest thousand grain weight was exhibited by Cross 2 RIL 12 and highest by Cross 3 RIL 23. Phenotypic variance was high (15.37) than genotypic variance (9.67). This exhibited moderate value for both heritability and expected genetic gain as per cent mean i.e 39.6 and 12.51, respectively.

Flag leaf area (cm²)

Flag leaf area exhibited significant genotypic difference with the lowest value for Cross 3 RIL 24 (21.64) and highest range value for Check 1, HUW 234 (36.50) and with the overall mean of 31.51. Phenotypic variance (13.44) was higher than genotypic variance (11.83). It showed high values for both heritability and expected genetic gain as per cent mean i.e. 78.8 and 21.65 respectively.

Chlorophyll content (SPAD unit)

Chlorophyll content showed significant genotypic difference and its range varied from 36.94 to 41.78. High chlorophyll content was shown by check PBN 51 (41.78) while Cross 1 RIL 6 (37.10) showed low chlorophyll content with the overall mean of 38.85. The phenotypic variance (4.77) was higher than genotypic variance (2.23). Heritability estimate and expected genetic gain as per cent mean both exhibited lower value i.e. 21.9 and 2.15 respectively.

Relative water content (%)

Relative water content exhibited significant genotypic difference and its range varied from 50.33 (Cross 2 RIL 18) to 63.72 (Cross 1 RIL 1) with a general mean value of 57.13. The genotypic covariance (6.23) and phenotypic variance (6.89) were almost equal. Heritability value was high (81.7) expected genetic gain as per cent mean was moderate (11.60) for this trait.

Relative water loss (%)

Relative water loss showed significant genotypic difference with check 2 i.e PBN 51 (67.52) recording minimum water loss and RIL 19 of cross 2 recorded maximum water loss (80.86) with the overall mean of 75.36. Phenotypic variance (4.71) was higher than genotypic variance (2.27). Heritability and expected genetic gain as per cent mean for this trait was low i.e. 23.3 and 2.26, respectively.

Canopy temperature (°C)

Among the physiological character studied genotypic differences were significant for canopy temperature. Canopy temperature ranged from as high as 27.29 (Cross 1 RIL 9) to low 16.83 for check 1 i.e. HUW 234 with a mean value of 21.51. The PCV (17.18) was greater than genotypic variance (11.37). Estimate of heritability and expected genetic gain as per cent mean were moderate for canopy temperature i.e. 43.8 and 15.50 respectively.

Canopy temperature depression ($^{\circ}\text{C}$)

Canopy temperature depression exhibited significant genotypic difference with lowest value for Cross 1 RIL 9 (5.92) and highest value for check 1 i.e. HUW 234 (8.25) with the overall mean of 7.54. This also showed lower values for both heritability and genetic advance as per cent mean i.e. 26.9 and 5.29 respectively. Phenotypic variance (9.56) was higher than genotypic variance (4.95). Heritability as well as genetic advance for this character was low i.e. 26.9 and 5.29 respectively.

Grain yield per plant (g)

Mean sum of square for grain yield per plant exhibit highly significant genotypic difference with highest and lowest range varying from low 14.41 to high (20.15). Maximum grain yield was recorded by heat tolerant check PBN 51 whereas minimum grain yield was exhibited by RIL 6 of cross 1. Overall mean value for grain yield was 16.47. Phenotypic variance (9.47) was higher than genotypic variance (7.18) for this character. Grain yield per plant exhibited moderate value for both heritability and genetic advance as per cent mean i.e. 57.5 and 11.21, respectively.

4.3 Character association

In order to find out the degree and direction of relationship of the yield contributing character with yield and inter relationship between them, correlation (phenotypic and genotypic) coefficient analysis was carried out for 13 traits under investigation. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component character on which selection can be based for genetic improvement in yield.

The correlation coefficient analysis of different trait was presented in table 6 and 7 for genotypic correlations and phenotypic correlations respectively.

Genotypic correlation analysis

Grain yield per plant exhibited significant positive correlation with plant height (0.367**), tillers per plant (0.222*), and chlorophyll content (0.362**) whereas canopy

temperature (-0.402), grains per ear (-0.799**), relative water loss (-0.392**) and canopy temperature depression (-0.857**) exhibited significant negative correlation with grain yield per plant. However, flag leaf area (0.064) exhibited positive correlation with grain yield per plant whereas number of days to maturity (-0.152), number of days to fifty percent flowering (-0.009) and relative water content (-0.008) showed negative correlation with grain yield per plant.

Days to flowering showed significant positive correlation with days to maturity (0.474**), positive correlation was also observed with plant height (0.059), tillers per plant (0.186), grains per ear (0.123), chlorophyll content (0.153), relative water content (0.026) and canopy temperature (0.134). Further, it showed significant negative correlation with thousand grain weight (-0.338), flag leaf area (-0.047**) and relative water loss (-0.287**) and negative correlation with canopy temperature depression (-0.011).

Days to maturity showed significant positive correlation with tillers per plant (0.324**), flag leaf area (0.350**), relative water content (0.241*) and canopy temperature depression (0.266*). Further it also recorded positive correlation with plant height (0.062), relative water loss (0.191), canopy temperature (0.060). Grains per ear (-0.089) and chlorophyll content (-0.085) showed negative correlation with days to maturity.

Plant height showed significant positive correlation with tillers per plant (0.709**), flag leaf area (0.244*), chlorophyll content (0.320**) and relative water content (0.474**). Further it also showed positive correlation with thousand grain weight (0.148). Grains per ear (-0.264**) and relative water loss (-0.489**) whereas canopy temperature depression (-0.534**) showed significant negative correlation with plant height.

Number of tillers per plant showed significant positive correlation with thousand grain weight (0.384**), flag leaf area (0.529**), and chlorophyll content (0.537**) exhibited significant positive correlation and grain yield whereas positive correlation with canopy temperature (0.024) and relative water content (0.194), while with number of grains per ear (-0.029) it showed negative correlation.

Grains per ear showed highest significant positive correlation with relative water loss (0.605**) followed by flag leaf area (0.360**), canopy temperature (0.249*) and

Table 6: Genotypic correlations coefficient among thirteen characters for 32 genotypes of wheat

	Number of days to fifty percent flowering	Number of days to maturity	Plant height (cm)	Number of tillers per plant	Number of grains per ear	Thousand grain weight (g)	Flag leaf area (cm ²)	Chlorophyll content (SPAD Unit)	Relative water content (%)	Relative water loss (%)	Canopy temperature (⁰ C)	Canopy temperature depression (⁰ C)	Grain yield ⁻¹ (g)
Number of days to fifty percent flowering		0.474**	0.059	0.186	0.123	-0.338**	-0.047**	0.153	0.026	-0.287**	0.134	-0.011	-0.009
Number of days to maturity			0.062	0.324**	-0.089	-0.324**	0.350**	-0.085	0.241*	0.191	0.060	0.226*	-0.152
Plant height (cm)				0.709**	-0.264*	0.148	0.244*	0.320**	0.474**	-0.489**	-0.173	-0.534**	0.367**
Number of tillers per plant					-0.029	0.384**	0.529**	0.537**	0.194	-0.370**	0.024	-0.478**	0.222*
Number of grains per ear						-0.227*	0.360**	-0.664**	-0.157	0.605**	0.249*	0.007**	-0.799**
Thousand grain weight (g)							-0.087	0.019	0.221*	0.321*	0.134	-0.040	-0.197
Flag leaf area (cm²)								0.275**	0.309**	0.513**	-0.089	0.076	0.064
Chlorophyll content (SPAD Unit)									0.082	-0.617**	0.310**	-0.646	0.362**
Relative water content (%)										0.065	-0.042	-0.084	-0.008
Relative water loss (%)											-0.350**	0.744**	-0.392**
Canopy temperature (⁰ C)												-0.073	-0.402**
Canopy temperature depression (⁰ C)													-0.857*

*,** significantly at 5% and 1% levels, respectively

canopy temperature depression (.007**) and whereas it showed significant negative correlation with thousand grain weight (-0.227*) and negative correlation with relative water content (-0.157).

Thousand grain weight showed highest significant positive correlation with relative water loss (0.321*) followed by relative water content (0.221*) and positive correlation with chlorophyll content (0.019), and canopy temperature (0.134). Other character such as flag leaf area (-0.087) and canopy temperature depression (-0.040) showed negative correlation with thousand grain weight.

Flag leaf area showed significant positive correlation with chlorophyll content (0.275**), relative water content (0.309**), relative water loss (0.513**) and positive correlation with canopy temperature depression (0.076) and negative correlation with canopy temperature (-0.089).

Chlorophyll content showed significant positive correlation with canopy temperature (0.310**) and positive correlation with relative water content (0.082). Further it showed significant negative correlation with relative water loss (-0.617**) and negative correlation with canopy temperature depression (-0.646).

Relative water content showed positive correlation with relative water loss (0.065) while other character such as canopy temperature (-0.042) and canopy temperature depression (-0.084) showed negative correlation with relative water content.

Relative water loss showed significant positive correlation with canopy temperature depression (0.744**) whereas it showed negative significant correlation with canopy temperature (0.350**).

Canopy temperature showed negative correlation with canopy temperature depression (-0.073).

Phenotypic correlation analysis

Grain yield per plant exhibited positive correlation with days to fifty per cent flowering (0.037) plant height (0.194), tillers per plant (0.116), flag leaf area (0.003)

relative water content (0.026) and chlorophyll content (0.166). Characters such as relative water loss (-0.235*), canopy temperature depression (-0.409*), showed significant negative correlation, however, character such as thousand grain weight (-0.774) and day to maturity (-0.041) showed negative correlation with grain yield per plant.

Day to fifty percent flowering showed significant positive correlation with tillers per plant (0.243*) significant negative correlation with days to maturity (-0.269**) and thousand grain weight (-0.217*). Character such as plant height (0.078), grains per ear (0.087). Chlorophyll content (0.052), relative water content (0.104), canopy temperature (0.111) and canopy temperature depression (0.027) exhibited positive correlation with days to flowering. Flag leaf area (-0.053) showed negative correlation with days to flowering.

Days to maturity showed significant positive correlation with canopy temperature depression (0.211*) and positive correlation with tillers per plant (0.145), grains per ear (0.179), flag leaf area (0.190), chlorophyll content (0.055), relative water content (0.150) and canopy temperature (0.107). It showed negative correlation with plant height (-0.073) and thousand grain weight (0.142).

Relative water content (0.284*) and tillers per plant (0.318**) exhibit significant positive correlation with plant height. Plant height also exhibited positive correlation with flag leaf area (0.182), thousand grain weight (0.157), flag leaf area (0.182), chlorophyll content (0.075). Character such as grain per ear (-0.149), canopy temperature (-0.105), relative water loss (-0.055), canopy temperature depression (-0.154) showed negative correlation with plant height.

Tillers per plant shows significant positive correlation with flag leaf area (0.303**) and relative water content (0.265**) whereas grains per ear (0.002), chlorophyll content (0.188) and canopy temperature (0.088) showed positive correlation with tillers per plant. Relative water loss (-0.215*) showed significant negative correlation with tillers per plant. Canopy temperature depression (-0.028) and thousand grain weight (-0.124) showed negative correlation with tillers per plant.

Canopy temperature depression (0.286**) and canopy temperature (0.226*) showed significant positive correlation with number of grains per ear. Number of grains

Table 7: Phenotypic correlations coefficients among thirteen characters for 32 genotypes of wheat

	Number of days to fifty percent flowering	Number of days to maturity	Plant height (cm)	Number of tillers per plant	Number of grains per ear	Thousand grain weight (g)	Flag leaf area (cm ²)	Chlorophyll content (SPAD Unit)	Relative water content (%)	Relative water loss (%)	Canopy temperature (°C)	Canopy temperature depression (°C)	Grain yield ¹ (g)
Number of days to fifty percent flowering		-0.269**	0.078	0.243*	0.087	-0.217*	-0.053	0.052	0.104	-0.099	0.111	0.027	0.037
Number of days to maturity			-0.073	0.145	0.179	-0.142	0.190	0.055	0.150	-0.005	0.107	0.211*	-0.041
Plant height (cm)				0.318**	-0.149	0.157	0.182	0.075	0.248*	-0.055	-0.105	-0.154	0.194
Number of tillers per plant					0.002	-0.124	0.303**	0.188	0.265**	-0.215*	0.088	-0.028	0.116
Number of grains per ear						0.119	0.142	-0.080	-0.082	0.178	0.226*	0.286**	-0.326**
Thousand grain weight (g)							-0.069	0.043	0.105	0.170	0.078	-0.094	-0.774
Flag leaf area (cm²)								0.026*	0.216*	0.187	-0.084	-0.082	0.003
Chlorophyll content (SPAD Unit)									0.051	-0.222*	0.066	-0.203*	0.166
Relative water content (%)										0.067	0.052	-0.016	0.026
Relative water loss (%)											-0.044	0.234*	-0.235*
Canopy temperature (°C)												0.113	-0.174
Canopy temperature depression (°C)													-0.409**

*,** significantly at 5% and 1% levels, respectively

per ear showed positive correlation with flag leaf area (0.142), relative water loss (0.178) and thousand grain weight (0.119). Chlorophyll content (-0.080) and relative water content (-0.082) showed negative correlation with number of grains per ear.

Chlorophyll content (0.043), relative water content (0.105), relative water loss (0.170) and canopy temperature (0.078) showed positive correlation with thousand grain weight. Thousand grain weight showed negative correlation with flag leaf area (-0.069) and canopy temperature depression (-0.094).

Flag leaf area exhibited highest significant positive correlation with relative water content (0.216*) followed by chlorophyll content (0.026*). Character such as canopy temperature depression (-0.082) and canopy temperature (-0.084) showed negative correlation whereas relative water loss (0.187) showed positive correlation with flag leaf.

Chlorophyll content exhibited positive correlation with relative water content (0.051) and canopy temperature (0.066). Remaining character such as relative water loss (-0.222*) and canopy temperature depression (-0.203*) show significantly negative correlation with chlorophyll content.

Relative water content exhibited positive correlation with canopy temperature (0.052) relative water loss (0.067). However, canopy temperature depression (-0.016) show negative correlation with relative water content.

Relative water loss showed significant positive correlation with canopy temperature depression (0.234*) whereas it shows negative correlation with canopy temperature (-0.044). Canopy temperature showed positive correlation with canopy temperature depression (0.113).

4.4 Path coefficient analysis

In the present study path coefficient analysis was carried out for grain yield per plant. Genotypic and phenotypic path diagram of yield component effects on grain yield in wheat for thirty two wheat genotypes is presented in fig.1 and 2 respectively. The direct and indirect effect of different component characters and physiological characters with

grain yield per plant at genotypic and phenotypic level are tabulated in table 8 and 9 respectively.

Genotypic path correlation

Since correlation studies alone are not sufficient to make picture of association analysis very clear, hence the assessment of real contribution of an individual character towards grain yield per plant becomes essential. Path coefficient provides a clear and more realistic picture of a complex situation that exists at correlation level. It measures the direct as well as indirect effect of one variable on the dependent variable through the other traits.

a) Direct effects

A critical perusal of path coefficient analysis in which diagonal values is direct effects revealed that flag leaf area (1.470) had highest positive direct effect on grain yield per plant followed by plant height (0.742), number of days to fifty percent flowering (0.185) and number of days to maturity (0.104). The negative direct effect was recorded for canopy temperature (-0.046), relative water content (-0.463), chlorophyll content (-0.599), grains per ear (-0.381), tillers per plant (-1.680), relative water loss (-0.491), canopy temperature depression (-1.100).

b) Indirect effect

Canopy temperature had significantly negative correlation (-0.402**) with grain yield. Characters viz, relative water content (0.020), relative water loss (0.172), canopy temperature depression (0.081), days to fifty per cent flowering (0.025) and days to maturity (0.006) showed positive indirect effect whereas plant height (-0.128), chlorophyll content (-0.186), grains per ear (-0.095), tillers per plant (-0.041), flag leaf area (-0.130) and thousand grain weight (-0.078) had indirect negative effect through canopy temperature.

Major contribution towards positive significant correlation between plant height and grain yield per plant (0.367**) came from direct positive effect (0.742) of plant height as well as indirect positive effect from canopy temperature (0.008), grains per ear (0.101), flag leaf area (0.359), relative water loss (0.240), canopy temperature depression (0.588),

Table 8: Genotypic path showing direct (diagonal) and indirect (off diagonal) effect of twelve characters on grain yield for 32 wheat genotype at phenotypic level

	Canopy temperature (°C)	Plant height (cm)	Relative water content (%)	Chlorophyll content (SPAD Unit)	Number of grains per ear	Number of tillers per plant	Flag leaf area (cm ²)	Relative water loss (%)	Canopy temperature depression (°C)	Number of days to fifty percent flowering	Number of days to maturity	Thousand grain weight (g)	Genotypic correlation with Grain yield ⁻¹
Canopy temperature (°C)	-0.046	-0.128	0.020	-0.186	-0.095	-0.041	-0.130	0.172	0.081	0.025	0.006	-0.078	-0.402**
Plant height (cm)	0.008	0.742	-0.219	-0.191	0.101	-1.191	0.359	0.240	0.588	0.011	0.007	-0.086	0.367**
Relative water content (%)	0.002	0.351	-0.463	-0.049	0.060	-0.325	0.455	-0.032	0.092	0.005	0.025	-0.128	-0.008
Chlorophyll content (SPAD Unit)	-0.014	0.237	-0.038	-0.599	0.253	-0.903	0.404	0.303	0.711	0.028	-0.009	-0.011	0.362**
Number of grains per ear	-0.012	-0.196	0.073	0.398	-0.381	0.049	0.530	-0.297	-1.108	0.023	-0.009	0.132	-0.799**
Number of tillers per plant	-0.001	0.526	-0.090	-0.322	0.011	-1.680	0.778	0.182	0.526	0.034	0.034	0.224	0.222*
Flag leaf area (cm ²)	0.004	0.181	-0.143	-0.165	-0.137	-0.890	1.470	-0.252	-0.083	-0.009	0.036	0.051	0.064
Relative water loss (%)	0.016	-0.363	-0.030	0.369	-0.231	0.622	0.753	-0.491	-0.818	-0.053	0.020	-0.187	-0.392**
Canopy temperature depression (°C)	0.003	-0.396	0.039	0.387	-0.384	0.804	0.111	-0.365	-1.100	-0.002	0.023	0.023	-0.857**
Number of days to fifty per cent flowering	-0.006	0.044	-0.012	-0.092	-0.047	-0.312	-0.069	0.141	0.012	0.185	-0.049	0.197	-0.009
Number of days to maturity	-0.003	0.046	-0.111	0.051	0.034	-0.545	0.514	-0.094	-0.248	-0.088	0.104	0.189	-0.152
Thousand grain weight (g)	-0.006	0.110	-0.102	-0.011	0.087	0.646	-0.128	-0.158	0.044	-0.063	-0.034	-0.582	-0.197

*,** significantly at 5% and 1% levels, respectively

Residual effect = 0.856

number of days to fifty percent flowering (0.011) and number of days to maturity (0.007) whereas relative water content (-0.219), chlorophyll content (-0.191), tillers per plant (-1.191) and thousand grain weight (-0.086) showed negative indirect effect via plant height.

Seven traits viz. canopy temperature (0.002), plant height (0.351), grains per ear (0.060), flag leaf area (0.455), canopy temperature depression (0.092), number of days to fifty percent flowering (0.005) and days to maturity (0.025) showed positive indirect effect whereas chlorophyll content (-0.049), tillers per plant (-0.325), relative water loss (-0.032) and thousand grain weight (-0.128) reported negative indirect effect via relative water content.

Significant positive correlation of chlorophyll content (0.362), had positive indirect effect via plant height (0.237), grains per ear (0.235), flag leaf area (0.404), relative water loss (0.303), canopy temperature depression (0.711) and days to fifty per cent flowering. (0.028).

Canopy temperature (-0.014), relative water content (-0.038), tillers per plant (-0.903) days to maturity (-0.009) and thousand grain weight (-0.011) showed negative indirect effect via chlorophyll content.

Number of grain per ear had significant negative correlation with grain yield. Negative value had indirect contribution of trait viz canopy temperature (-0.012), plant height (-0.196), canopy temperature depression (-1.108) and days to maturity (-0.009) via number of grains per ear and its direct effect of -0.381 whereas character such as relative water content (0.073), chlorophyll content (0.398), tillers per plant (0.049), flag leaf area (0.530), days to fifty percent flowering (0.023) and thousand grain weight (0.132) showed positive indirect effect.

Tillers per plant showed positive significant correlation (.222*) with grain yield per plant but it exerted negative direct effect (-1.680) on grain yield per plant whereas plant height (0.526), grains per ear (0.011), flag leaf area (0.778), relative water loss (0.182), canopy temperature depression (0.526), number of days to fifty percent flowering (0.034) and days to maturity (0.034) contributed positive indirect effect to grain yield per plant.

Canopy temperature (-0.001), relative water content (-0.090), chlorophyll content (-0.322) decreased the magnitude of correlation via tillers per plant.

Flag leaf area exhibited positive correlation with grain yield per plant (0.064), characters viz canopy temperature (0.004), plant height (0.181), number of days to maturity (0.036) and thousand grain weight (0.051) showed indirect positive effect along with positive direct effect of flag leaf area (1.470), and characters like relative water content (-0.143), chlorophyll content (-0.165), grains per ear (-0.137), tillers per plant (-0.890), relative water loss (-0.252), canopy temperature depression (-0.083) and days to fifty percent flowering (-0.009) had negative indirect effect via flag leaf area.

Five character viz canopy temperature (0.016) , chlorophyll content (0.369), tillers per plant (0.622), flag leaf area (0.753) and days to maturity (0.020) showed indirect positive effect whereas plant height (-0.363), relative water content (-0.030), grains per ear (-0.231), canopy temperature depression (-0.818), days to fifty percent flowering (-0.053) and thousand grain weight (-0.187) showed negative indirect effect via relative water loss exhibiting significant negative correlation (-0.392**) with grain yield.

Canopy temperature depression shows significant negative correlation with grain yield (-0.857**) due to its negative direct effect (-1.100) with grain yield as well as negative indirect effect contributing plant height (-0.396), grain per ear (-0.384), relative water loss (-0.365) and days to fifty percent flowering (-0.002) via canopy temperature. Other character such as canopy temperature (0.003), relative water content (0.039), chlorophyll content (0.387), tillers per plant (0.804), flag leaf area (0.111), days to maturity (0.023) and thousand grain weight (0.023) showed indirect effect via canopy temperature depression.

Plant height (0.044), relative water loss (0.141), canopy temperature depression (0.012), and thousand grain weight (0.197) showed positive indirect effect whereas canopy temperature (-0.006), relative water content (-0.012), chlorophyll content (-0.092), grains per ear (-0.047), tillers per plant (-0.312), flag leaf area (-0.069) and days to maturity (-0.049) showed negative direct effect via days to flowering.

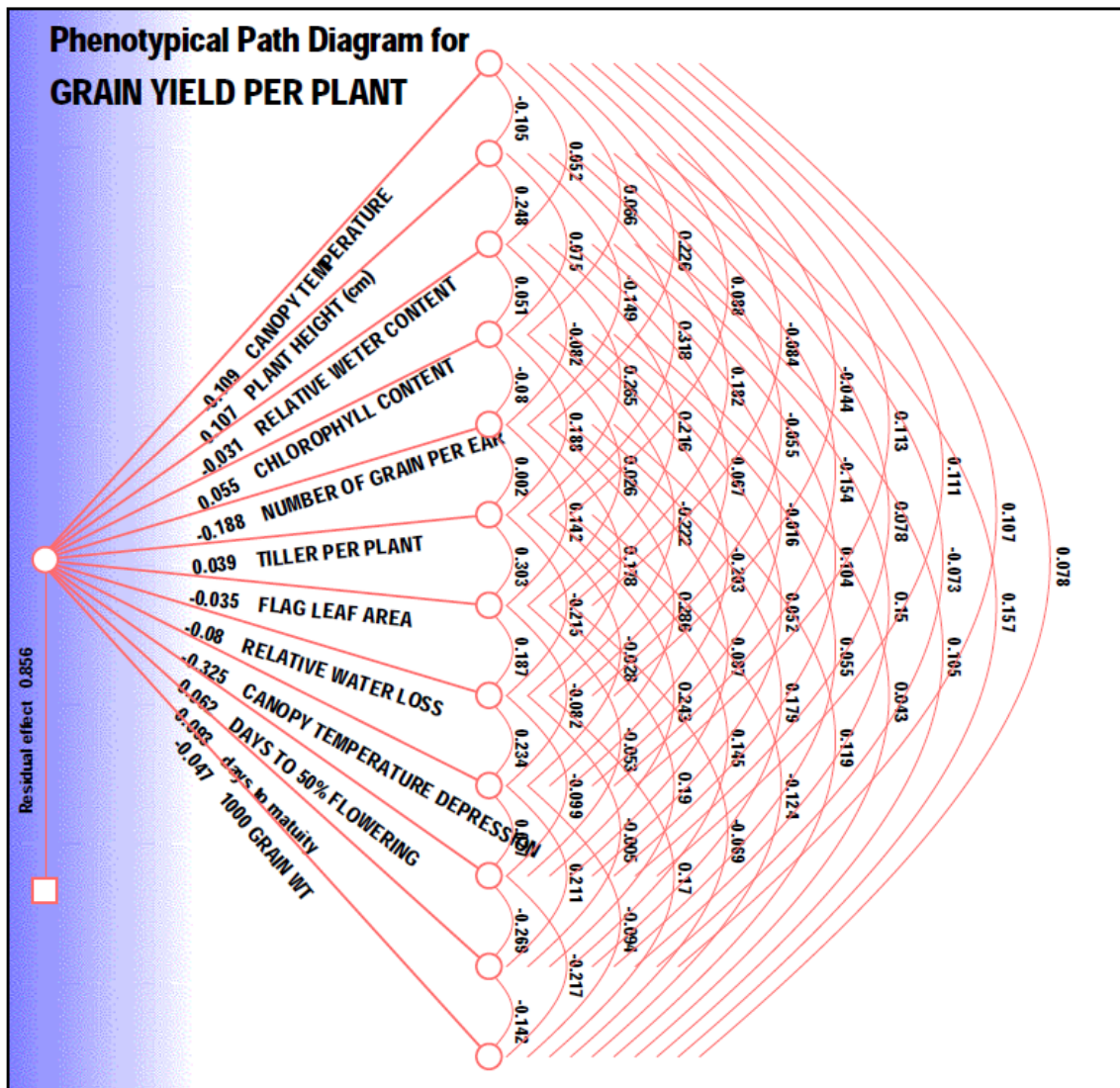


Fig.2: Phenotypic Path diagram of yield component effect on grain yield in wheat for thirty two wheat genotypes

Table 9: Phenotypic path showing direct (diagonal) and indirect (off diagonal) effect of twelve characters on grain yield for 32 wheat genotype at phenotypic level

	Canopy temperature (°C)	Plant height (cm ²)	Relative water content (%)	Chlorophyll content (SPAD Unit)	Number of grains per ear	Number of tillers per plant	Flag leaf area (cm ²)	Relative water loss (%)	Canopy temperature depression (°C)	Number of days to fifty percent flowering	Number of days to maturity	Thousand grain weight (g)	Phenotypic correlation with grain yield ⁻¹
Canopy temperature (°C)	-0.109	-0.011	-0.002	0.004	-0.043	0.004	0.003	0.004	-0.037	0.007	0.010	-0.004	-0.174
Plant height (cm²)	0.011	0.107	-0.008	0.004	0.028	0.013	-0.006	0.004	0.050	0.005	-0.007	-0.007	0.194
Relative water content (%)	-0.006	0.026	-0.031	0.003	0.015	0.011	-0.007	-0.005	0.005	0.006	0.014	-0.005	0.026
Chlorophyll content (SPAD Unit)	-0.007	0.008	-0.002	0.055	0.015	0.007	-0.001	0.018	0.066	0.003	0.005	-0.002	0.166
Number of grains per ear	-0.025	-0.016	0.003	-0.004	-0.188	0.000	-0.005	-0.014	-0.093	0.005	0.017	-0.006	-0.326**
Number of tillers per plant	-0.010	0.034	-0.008	0.010	0.000	0.040	-0.010	0.017	0.009	0.015	0.013	0.006	0.116
Flag leaf area (cm²)	0.009	0.019	-0.007	0.001	-0.027	0.012	-0.035	-0.015	0.027	-0.003	0.018	0.003	0.003
Relative water loss (%)	0.005	-0.006	-0.002	-0.012	-0.033	-0.009	-0.006	-0.081	-0.076	-0.006	0.000	-0.008	-0.235*
Canopy temperature depression (°C)	-0.012	-0.016	0.001	-0.011	-0.054	-0.001	0.003	-0.019	-0.324	0.002	0.020	0.004	-0.409**
Number days to fifty percent flowering	-0.012	0.008	-0.003	0.003	-0.016	0.010	0.002	0.008	-0.009	0.061	-0.025	0.010	0.037
Number of days to maturity	-0.012	-0.008	-0.005	0.003	-0.034	0.006	-0.007	0.000	-0.068	-0.017	0.092	0.007	-0.041
Thousand grain weight (g)	-0.008	0.017	-0.003	0.002	-0.022	-0.005	0.002	-0.014	0.030	-0.013	-0.013	-0.047	-0.074

*,** significantly at 5% and 1% levels, respectively

Residual effect = 0.856

Thousand grain weight showed negative correlation with grain yield (-0.192) per plant due to its direct negative effect (-0.582) and indirect negative effect via canopy temperature (-0.006), relative water content (-0.102), chlorophyll content (-0.011), flag leaf area (-0.128), relative water loss (-0.158), days to fifty percent flowering (-0.063) and days to maturity (-0.034). Plant height (0.110), grains per ear (0.087), tillers per plant (0.646) and canopy temperature depression (0.044) showed positive indirect effect via thousand grain weight.

Phenotypic path analysis

Direct effect

The results for phenotypic path coefficient analysis are presented in table 9. A critical perusal of phenotypic path coefficient analysis in which diagonal values are direct effects revealed that plant height (0.107) followed by days to maturity (0.092), days to fifty percent flowering (0.061), chlorophyll content (0.055) and tillers per plant (0.040), had positive direct effect on grain yield. Remaining character such as canopy temperature (-0.109), relative water content (-0.031), grain per ear (-0.188), flag leaf area (-0.035), relative water loss (-0.081), canopy temperature depression (-0.324), and thousand grain weight (-0.047) exhibited negative direct effect on grain yield.

Indirect effect

Negative correlation of canopy temperature with grain yield (-0.174) came from negative direct effect of canopy temperature (-0.109) and indirect negative effect via plant height (-0.011), relative water content (-0.002), grains per ear (-0.043), canopy temperature depression (-0.037), and thousand grain weight (-0.004) whereas chlorophyll content (0.004), tillers per plant (0.004), flag leaf area (0.003), relative water loss (0.004), days to fifty percent flowering (0.007) and days to maturity (0.010) exhibits indirect positive effect via canopy temperature.

Eight characters namely canopy temperature (0.011), chlorophyll content (0.004), grains per ear (0.028), tillers per plant (0.013), relative water loss (0.004), canopy temperature depression (0.050) and days to fifty per cent flowering (0.005) showed positive

indirect effect along with positive direct effect of plant height (0.107) with grain yield per plant (0.194) resulting in its positive correlation. Other character such as relative water content (-0.008) flag leaf area (-0.006), days to maturity (-0.007) and thousand grain weight (-0.007) showed negative indirect effect via plant height.

Relative water content recorded negative direct effect on grain yield per plant (-0.031) but trait viz plant height (0.026), chlorophyll content (0.003), grains per ear (0.015), tillers per plant (0.011), canopy temperature depression (0.005), days to fifty percent flowering (0.006) and days to maturity (0.014) showed positive indirect effect which resulted in positive correlation of grain yield per plant with relative water content. However canopy temperature (-0.006), flag leaf area (-0.007), relative water loss (-0.005) and thousand grain weight (-0.005) showed negative indirect effect via relative water content.

Positive indirect effect of plant height (0.008), grains per ear (0.015), tillers per plant (0.007), relative water loss (0.018), canopy temperature depression (0.066), days to fifty percent flowering (0.008) and days to maturity (0.005) along with positive direct effect of chlorophyll content (0.055) contributed to positive correlation of chlorophyll content with grain yield per plant. Canopy temperature (-0.007), relative water content (-0.002), flag leaf area (-0.001) and thousand grain weight (-0.002) showed indirect negative effect via chlorophyll content.

Relative water content (0.003), days to fifty percent flowering (0.005) and days to maturity (0.017) showed positive indirect effect whereas negative indirect effect of most of the trait such as canopy temperature depression (-0.093), plant height (-0.016), chlorophyll content (-0.004), flag leaf area (-0.005), relative water loss (-0.014), thousand grain weight (-0.066) and direct negative effect of grains per ear (-0.188) on grain yield per plant resulted in negative path correlation (-0.326**) of grains per ear on grain yield per plant.

Plant height (0.034), chlorophyll content (0.010), canopy temperature depression (0.009), days to fifty per cent flowering (0.015), days to maturity (0.013) and thousand grain weight (0.006) showed positive indirect effect with grain yield per plant which along

with positive direct effect of tillers per plant with grain yield per plant (0.040) resulted in their positive path correlation (0.116). Character such as relative water content (-0.008), canopy temperature (-0.010), relative water content (-0.008), flag leaf area (-0.010), showed negative indirect effect via tillers per plant.

Flag leaf area had positive correlation with grain yield per plant (0.003) which is contributed by positive indirect effect of canopy temperature (0.009), plant height (0.019), chlorophyll content (0.001), tillers per plant (0.012), canopy temperature depression (0.027), days to maturity (0.018) and thousand grain weight (0.003). Characters viz relative water content (-0.007), grain per ear (-0.027), relative water loss (-0.015), days to fifty per cent flowering (-0.003) showed negative indirect effect on grain yield via flag leaf area.

Major contribution towards negative significant correlation (-0.235*) between relative water loss and grain yield per plant came from its direct negative effect (-0.081) on grain yield per plant as well as indirect negative effect of plant height (-0.006), chlorophyll content (-0.012), tillers per plant (-0.009), canopy temperature depression (-0.076), thousand grain weight (-0.008), grains per ear (-0.033), relative water content (-0.002), days to fifty per cent flowering (-0.006) whereas only canopy temperature (0.005) showed positive indirect effect via relative water loss.

Five character namely relative water content (0.001), flag leaf area (0.003), days to fifty percent flowering (0.002), days to maturity (0.020) and thousand grain weight (0.004) showed positive indirect effect whereas canopy temperature (-0.012), plant height (-0.016), chlorophyll content (-0.011), grains per ear (-0.054), tillers per plant (-0.001), relative water loss (-0.019) showed negative indirect effect via canopy temperature depression exhibiting overall significant negative correlation (-0.409**) with grain yield per plant

Grain yield per plant exhibited positive correlation (0.037) with number of days to fifty percent flowering, positive correlation was due to its positive direct effect of days to fifty per cent flowering (0.061) and indirect positive effect via plant height (0.008), chlorophyll content (0.003), tillers per plant (0.010), flag leaf area (0.002), relative water loss (0.008) and thousand grain weight (0.010) Canopy temperature (-0.012), relative

water content (-0.003), grains per ear (-0.016), canopy temperature depression (-0.009) and days to maturity (-0.025) exhibited negative effect via number of days to fifty per cent flowering.

Although number of days to maturity showed positive direct effect (0.092) on grain yield per plant but it exhibited negative correlation with grain yield per plant (-0.041) due to negative indirect of most of the characters such as canopy temperature (-0.012), plant height (-0.008), relative water content (-0.005), grains per ear (-0.034), flag leaf area (-0.007), canopy temperature depression (-0.068) and days to fifty per cent flowering (-0.017) via days to maturity. Characters viz. chlorophyll content (0.033), tillers per plant (0.066), thousand grain weight (0.007) showed positive direct effect via number of days to maturity.

Thousand grain weight exhibited negative correlation (-0.074) with grain yield per plant due to its negative direct effect (-0.047). Plant height (0.017), chlorophyll content (0.002), flag leaf area (0.002), canopy temperature depression (0.030) showed positive indirect effect whereas canopy temperature (-0.008), relative water content (-0.003), grains per ear (-0.022), tillers per plant (-0.005), relative water loss (-0.014), days to fifty percent flowering (-0.013) and days to maturity (-0.013) showed negative indirect effect via thousand grain weight.

4.5 Genetic divergence analysis.

Based on Mahalanobis D^2 analysis (Mahalanobis, 1936) thirty two genotypes were grouped into six clusters depicted in table 10. This indicated that the presence of moderate diversity of genotypes. Cluster 1 had maximum genotypes namely twenty five (Cross 1 RIL 1, 2, 3, 4, 5, 6, 7, 8 and 10. Cross 2 RIL 11, 12, 13, 14, 16, 17, 18, 19 and 20. Cross 3 RIL 21, 22, 26, 27, 29. Check HUW 234.) followed by cluster fifth having three genotype (Cross 1 RIL 9, Cross 3 RIL 24, 28), second cluster having one genotype (Cross 3 RIL 5), third cluster also has one genotype (Cross 2 RIL 5), fourth cluster has only one check genotype PBN 51 and cluster sixth also with one RIL 10 of cross 3.

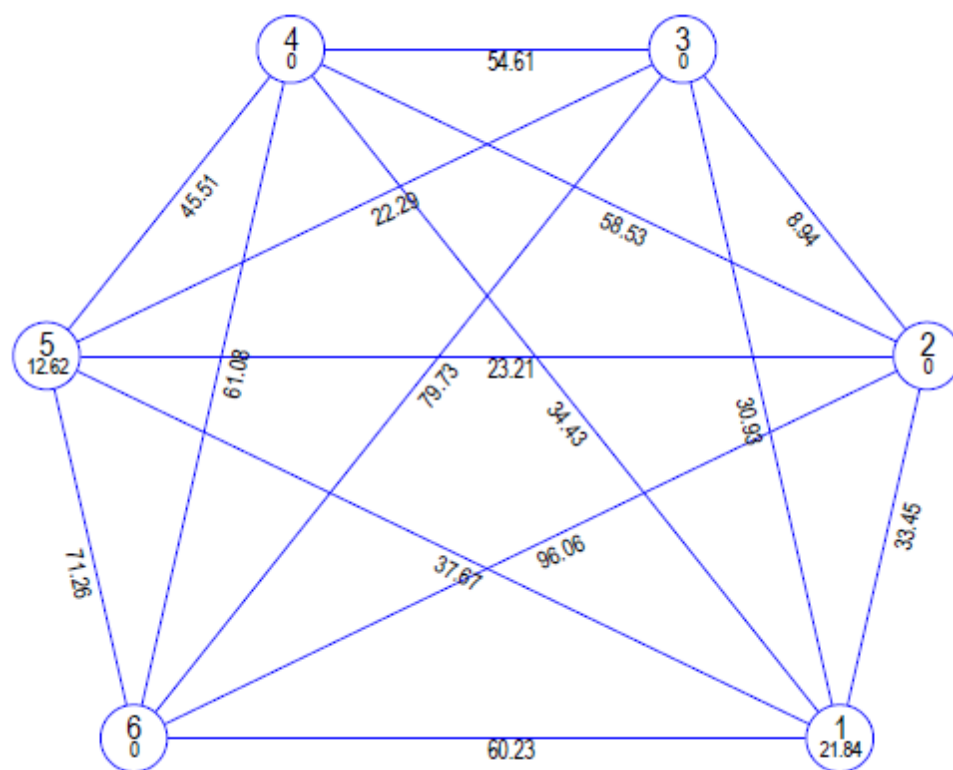


Fig.3: Mahalanobis Euclidean distance representing average intra and inter cluster between 32 wheat genotypes

Table 10: Distribution pattern of 32 genotypes of wheat in various clusters (I-VI) for various heat related traits.

Clusters No.	No. of Genotype	Name of Genotypes
I	25	Cross 1 RIL 1, 2, 3, 4, 5, 6, 7, 8 and 10. Cross 2 RIL 11, 12, 13, 14, 16, 17, 18, 19 and 20. Cross 3 RIL 21, 22, 26, 27 and 29. Check HUW 234
II	1	Cross 3 RIL 15
III	1	Cross 2 RIL 15
IV	1	Check PBN 51
V	3	Cross 1 RIL 9, Cross 3 RIL 24,28
VI	1	Cross 3 RIL 30

Table 11: Inter (off diagonal) and intra (diagonal) cluster average of D^2 among different clusters in wheat to study genetic divergence among various RILs

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	21.82	33.45	30.93	34.43	37.67	60.23
Cluster II		0.00	8.94	58.53	23.21	96.06
Cluster III			0.00	54.61	22.29	79.73
Cluster IV				0.00	45.51	61.08
Cluster V					12.62	71.26
Cluster VI						0.00

Table 12: Cluster mean values of different clusters for various characters of 32 wheat genotype

Character/Cluster	I	II	III	IV	V	VI
Number of days to fifty percent flowering	97.90	103.67	101.45	102.00	103.33	78.67
Number of days to maturity	120.13	105.33	122.33	117.67	108.67	128.67
Plant height (cm)	86.20	72.54	69.51	116.78	82.35	76.36
Number of tillers per plant	9.07	8.56	9.22	10.60	8.19	8.33
Number of grains per ear	41.07	41.89	39.78	37.09	38.55	37.78
Thousand grain weight (g)	30.36	36.71	29.34	33.67	30.32	33.29
Flag leaf area (cm²)	32.91	31.76	31.15	31.43	22.04	25.33
Chlorophyll content (SPAD unit)	38.66	38.88	41.44	41.78	38.31	38.47
Relative water content (%)	57.55	54.48	53.18	59.59	55.87	50.88
Relative water loss (%)	75.90	74.10	76.40	67.52	73.84	74.74
Canopy temperature (°C)	21.54	26.87	21.03	20.65	21.01	21.51
Canopy temperature depression (°C)	7.64	7.27	7.30	6.22	7.50	7.14
Grain yield¹ (g)	16.21	16.77	16.42	20.16	16.80	18.08

Table 13: Percent contribution towards variability of each character for 32 wheat genotype for various heat related traits.

S.No	Character	Contribution %
1	Number of days to fifty per cent flowering	40.32
2	Number of days to maturity	7.46
3	Plant height (cm)	2.02
4	Number of tillers per plant	3.63
5	Number of grains per ear	1.01
6	Thousand Grain weight (g)	2.02
7	Flag leaf area (cm²)	15.52
8	Chlorophyll content (SPAD Unit)	6.00
9	Relative water content (%)	16.94
10	Relative water loss (%)	2.22
11	Canopy temperature (°C)	1.41
12	Canopy temperature depression (°C)	2.02
13	Grain yield ⁻¹ (g)	4.48

Intra and inter cluster distances

The intra and inter cluster distance values between seven clusters is presented in table 11. The genotype of the cluster II and VI exhibited maximum divergence (96.06) followed by the genotypes of cluster III and VI (79.73), V and VI (71.26), IV and VI (61.08), I and VI (60.23), II and IV (58.53), III and IV (54.61), IV and V (45.51), I and V (37.67), IV and I (34.43), I and II (33.45), I and III (30.93), II and V (23.21), III and V (22.29) and II and III (8.94). The higher inter cluster distance indicated the presence of more diversity among the genotypes included among these clusters. The average intra cluster distance between the genotypes of cluster I (21.82) was maximum followed by clusters V (12.62) as shown in fig. 3.

Cluster means of different clusters for various characters

Mean values of seven clusters of 32 genotypes under timely sown condition is presented in Table 12. Difference in cluster means existed for all characters. For days to fifty per cent flowering cluster II (103.67) had high mean value whereas cluster VI (78.67) showed lowest mean value. Days to maturity had highest mean value for Cluster VI (128.67) and lowest for Cluster II (105.33). For plant height cluster IV showed high mean (116.78) whereas lowest mean was observed in cluster III (69.51). Tillers per plant had highest mean value for cluster IV (10.00) and lowest for cluster V (8.19). Grains per ear had highest mean in cluster II (41.89) and lowest in cluster IV (37.09). For thousand grain weight highest mean was observed for Cluster II (36.71) and lowest for Cluster III (29.34). Flag leaf area showed highest mean for cluster I (32.91) and lowest for cluster V (22.04). Cluster IV (41.78) had highest whereas cluster V (38.31) had lowest mean for chlorophyll content. For relative water content cluster IV (59.59) had high relative water content and cluster VI (50.88) had lower cluster mean. Relative water loss had high mean for Cluster III (76.40) while Cluster IV (67.52) showed low mean value. Canopy temperature had highest mean value of 26.87 in cluster II and lowest mean for cluster V (21.01). For Canopy temperature depression highest value was shown by cluster I (7.64) and lowest for cluster IV (6.22). For grain yield per plant highest cluster mean was observed for Cluster IV (20.16) and lowest for Cluster I (16.21).

Percent contribution towards total divergence

Percent contribution towards total divergence was calculated as per Mahalanobis D^2 statistic (Mahalanobis, 1936). The maximum contribution towards the total divergence as given in table 13 was exhibited by days to flowering (40.32%), followed by relative water content (16.44), flag leaf area (15.52), days to maturity (7.46%), chlorophyll content (6%), grain yield per plant (4.48), tillers per plant (3.63%), relative water loss (2.22%), plant height (2.02%), grain weight (2.02%), canopy temperature depression (2.02%), canopy temperature (1.41%) and lowest contribution was for grain per ear (1.01). The trait viz. days to flowering, relative water content, flag leaf area, number of days to maturity, chlorophyll content and grain yield contributed more than 70% towards divergence. Hence, these characters should be given importance during hybridization and selection in the segregating population for improvement of yield and its component traits.

Chapter-5

Discussion

DISCUSSION

Wheat is the most important stable food crop for more than one third of the world population and contributes more calories and proteins to the world diet than any other cereal crops (Shewry *et al.*, 2009). Wheat is cultivated on 30% of world's cereal area and provides food to 36% of the global population. By sharing 12% in global wheat production India is ranked as second largest wheat producing country. Global total wheat utilization in 2018-19 is forecast to increase by 0.4 percent from the 2017-18 estimated level, to reach an all-time high of 741.1 million tonnes. Utilization of wheat for direct human consumption is forecast to increase by 1.1 percent, to nearly 509 million tonnes, thus remaining broadly in line with the global population growth. (FAO 2018). Abiotic stresses are responsible for 50% reduction in wheat yield like high temperature (20%), salinity (10%), drought (9%), low temperature (7%) and other form of stresses (Kajla *et al.*, 2015). The optimum temperature for wheat at anthesis and grain filling ranged from 12 to 22°C and temperature above this causes drastic reduction in wheat yield (Farooq *et al.*, 2011). High temperature affects both vegetative as well as reproductive stages of plant but its drastic effect was more on reproductive stage (Sunita *et al.*, 2017). Heat stress is an international issue related to adverse effect on agriculture that causes morpho-physiological, anatomical and biochemical changes resulted in heavy losses in crop production (Wahid *et al.*, 2007). (Munjal and Rana 2003) observed that 3% to 4% reduction in yield with every 1°C rise in temperature. Abiotic stresses are the major constrains in the wheat production in which high temperature, drought, flood and other natural disasters have larger effects. Heat stress is one of the major abiotic stress that has adverse implications on wheat production especially in those areas where later development of crop deals with higher temperature.

Collection of genetic variability and its evaluation for various genetic parameters is an essential part of any crop improvement programme. For successful use of such new lines and germplasm in crossing programme, it was considered essential to have analysis of genetic divergence in new recombinant inbred lines developed using elite donors for that traits. Correlation analysis utilizing more of physiological components is important for

judicious choice of parents for developing heat tolerant line. Looking to these facts, it seems essential to identify and classify the RILs variability based on morphological distribution and genetic diversity. Present study was carried out to evaluate the genetic diversity among the new RILs developed using the heat tolerant donors for different morpho-physiological parameters contributing to grain yield and heat stress. Attempts have also been made to study the nature of association of grain yield with various morphological traits along with the relative contribution of direct and indirect effects of various traits on grain yield. Various biometrical techniques are now available for assessing the nature and magnitude of genetic variability. Burton. (1952) suggested that genetic variability along with heritability are important parameters to assess exact genetic potential of genotype. Estimate of heritability and genetic advance helps to develop direct selection strategy to choose appropriate germplasm lines as donor for hybridization programme (Johnson *et al.*, 1955). Genetic diversity is crucial for adaptability and survival of crop in different conditions. Hence, it is beneficial to assess the genetic diversity at a particular level that may facilitate the efficient exploitation of the germplasm. (Fu and Somers, 2009).

Hence the present study was undertaken to evaluate thirty RILs along with two checks of bread wheat genotype for various physiological and morphological traits. There were 98 days with more temperature above 25⁰C. There were several temperature peaks before and during flowering (Appendix-I). Results of the present study are discussed below in light of the available literature and explanation whenever possible is provided for the trends revealed by these observations under following heads.

- 5.1 Analysis of variance and component of variation
- 5.2 Genetic variability
- 5.3 Character association
- 5.4 Path correlation analysis
- 5.5 Genetic Divergence

Table 14: Top ranking five RILs for chlorophyll content, canopy temperature and grain per plant.

Genotype	Chlorophyll content (SPAD Unit)	Genotype	Canopy temperature (°C)	Genotype	Grain yield per plant (g)
CROSS 2 RIL 15	41.44	CROSS 3 RIL 27	17.42	CROSS 3 RIL 30	18.07
CROSS 3 RIL 23	40.52	CROSS 3 RIL 24	17.74	CROSS 1 RIL 8	17.75
CROSS 2 RIL 12	40.30	CROSS 3 RIL 22	17.87	CROSS 2 RIL 20	17.73
CROSS 3 RIL 24	40.09	CROSS 3 RIL 28	18.01	CROSS 3 RIL 27	17.65
CROSS 2 RIL 14	40.02	CROSS 2 RIL 17	18.28	CROSS 2 RIL 12	17.59

5.1 Analysis of variance and component of variation

In the present study thirty wheat RILs along with two check varieties of bread wheat were studied to assess their heat tolerance in terms of traits implicated in heat, yield and yield related traits. The analysis of variance clearly estimates indicated that mean sum of square were there was highly significant for all the characters under study. This indicates that there were significant differences in different morphological and physiological traits in the RILs and check varieties. The present findings corroborate the earlier reports of Palve and Raghavaiah. (2002) and Mahato and Kerketta. (2004) for number of days to maturity, number of grain per spike, chlorophyll content, thousand grain weight and grain yield per plant. Sharma and Panwar. (2010) reported similar results for plant height, number of tillers per plant, number of days to maturity, thousand grain weight and grain yield per plant. Wani *et al.* (2011) reported similar finding for days to maturity, plant height, number of tillers per plant, canopy temperature at grain filling and canopy temperature depression, Dobariya *et al.* (2006) reported for plant height, tillers per plant and grain yield per plant. Hassan *et al.* (2016) found highly significant differences among plant height, grain yield per plant and thousand grain weight whereas Rad *et al.* (2013) for significant difference for relative water content,

5.2 Variability analysis

Information on the nature and magnitude of genetic variability is of immense value for starting any breeding programme, because presence of considerable variability in the base material ensures efficient selection of desired plant types. The estimates of heritability, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and genetic advance are useful in determining the method of selection to improve a particular population for a specific trait. A perusal of Table 5 revealed that phenotypic coefficients of variance (PCV) was higher than genotypic coefficients of variance (GCV) for all the characters under study indicating that environment component also has influence on expression of these characters. These results are in conformation to the report of Maurya *et al.* (2014). Phenotypic and genotypic coefficient of variance was found to be moderate for tiller per plant, flag leaf area. Similar result was also reported Aharizad *et al.* (2012). However, in case of days to fifty percent flowering, days to maturity low level of PCV and

GCV was recorded by Bhushan *et al.* (2013). For plant height and thousand grain weight, PCV and GCV were moderate, Nukasani *et al.* (2013) reported moderate PCV and GCV for plant height and thousand grain weight. Heritability determines the extent of genetic control of a given trait and its transmission to progeny and, hence has bearing on the selection efficiency of trait concerned. Grain yield per plant and tillers per plant were found to have moderate heritability. Priya *et al.* (2013) similarly observed moderate heritability for number of tillers per plant and grain yield per plant. Moderate heritability was recorded for thousand grain weight which was reported by Kyosev *et al.* (2015) for thousand grain weight. Moderate heritability and moderate genetic gain as percent of mean was observed for grain yield per plant, canopy temperature, and thousand grain weight. Similar results were also obtained by Bhushan *et al.* (2013). Accordingly, in the present study high heritability with medium genetic gain as per cent of mean was observed with respect to grain yield per plant, relative water content, flag leaf area, plant height. Ali *et al.* (2008), Majumder *et al.* (2008) reported similar results for these traits. List of top ranking RILs based on grain yield per plant, canopy temperature and chlorophyll content is present in table 14. Heritability estimates along with genetic gain is more useful in predicting the resultant effect for selecting best individual than by heritability alone. (Johnson *et al.* 1955). Selection based on phenotypic performance does not lead to expected genetic advance due to undesirable association between characters. High genetic advance has been attributed to additive gene effect. High genetic advance and high heritability was revealed for number of days to fifty per cent flowering, plant height, flag leaf area and relative water content.

5.3 Character association

Genetic correlation among favourable combination of characters help increasing the efficiency of selection. Correlation arise primarily due to either genetic linkages, pleiotrophy or physiological and developmental relation. The result of present study recorded that number of tillers per plant, plant height and chlorophyll content was positively significantly correlated with grain yield per plant at genotypic level. Similar results were reported by Nukasani *et al.* (2013) for tillers per plant, plant height and chlorophyll content. Grain yield per plant exhibited positive correlation with plant height,

relative water content, number of tillers per plant and flag leaf area at phenotypic level. These results were in confirmation with Shankarrao *et al.* (2010), who observed positive correlation of grain yield per plant with similar characters at phenotypic level. Agarwal *et al.* (2005) reported significant and positive correlation of grain yield per plant with relative water content. Canopy temperature and relative water loss was found to be significantly negative correlated with grain yield at genotypic level. Similar results were also obtained by Sukumaran *et al.*, (2015) for canopy temperature and Khazaei *et al.* (2010) for relative water loss.

Relative water content showed positive correlation with thousand grain weight and tillers per plant at phenotypic level. This result was similar to the finding of Jaiswal *et al.* (2010) who also reported positive correlation of thousand grain weight and tillers per plant with relative water content. Chlorophyll content exhibited significant positive correlation with flag leaf area and tillers per plant and positive correlation with relative water content at genotypic level. This was similar to the finding of Ali *et al.* (2008). Number of days to maturity exhibited significant positive correlation with number of tillers per plant and flag leaf area and positive correlation with canopy temperature at genotypic level, this was also reported by Anwar *et al.*, (2009) for number of tillers per plant. Thousand grain weight exhibited positive correlation with plant height, chlorophyll content and positive significant correlation with relative water content whereas significant negative correlation with days to fifty percent flowering at both genotypic and phenotypic level. Similar results were also reported by Abou *et al.* (2007). Flag leaf area reported significant positive association with plant height, relative water content, grains per ear, tillers per plant and chlorophyll content whereas negative correlation with canopy temperature at genotypic level. This Indicated that increase in flag leaf area resulted in decrease in canopy temperature because canopy of plant increases with increase in flag leaf area which facilitates transpiration rate and helps in lowering down the canopy temperature and maintain cooler temperature than environment.

Therefore it can be concluded that plant height, chlorophyll content, tillers per plant showed significant positive correlation with grain yield per plant whereas it shows positive correlation with flag leaf area at genotypic level. At phenotypic level grain yield showed

positive correlation with plant height, relative water content, chlorophyll content, tillers per plant, flag leaf area and day to maturity. Hence selection for any one of these characters would bring in simultaneous improvement in grain yield. Canopy temperature showed significant negative correlation with grain yield per plant indicating that cooler canopy mitigates the effect of high temperature on grain yield. Similar reports were earlier presented by Shahidullah *et al.* (2017)

5.4 Path coefficient analysis

Since correlation studies alone are not sufficient to make picture of association analysis very clear, hence the assessment of real contribution of an individual character-towards grain yield becomes essential. Path coefficient analysis devised by Wright (1921) studies cause and effect relationship which helps in understanding the cause of apparent correlation and effect relationship which helps in understanding the cause of apparent correlation keeping in view the complex characters as grain yield, recourse was taken to path coefficient analysis technique proposed by Dewey and Lu (1959). Path coefficient provides a clear and more realistic picture of a complex situation that exists due to correlation among various traits. It measures the direct as well as indirect effect of one variable on the dependent variable through the other traits.

The correlation coefficient indicated the relationship between pair of characters. But dependent character is an interaction of product of much mutually associated component character and change in any one component character will disturb whole network of cause and effect system. The success of breeding programme depends upon contribution of individual component character on complex character like grain yield. It is statistical device which is unique in portioning the association into direct and indirect effect through other dependent variables.

Chlorophyll content, tillers per plant showed significantly positive correlation with grain yield per plant whereas significant negative correlation of relative water loss and canopy temperature with grain yield per plant was observed at genotypic level. Similar finding were also reported by Kaddem *et al.* (2014).

A critical perusal of path coefficient analysis revealed that, plant height, number of days to maturity, number of days to fifty percent flowering have positive direct effect with grain yield per plant at both phenotypic and genotypic level. Chlorophyll content, number of grains per ear, number of tillers per plant showed positive direct effect with grain yield per plant at phenotypic level. Canopy temperature exhibited significant negative correlation with grain yield due to direct negative direct effect with grain yield and indirect negative effect due to relative water content, chlorophyll content, number of grain per ear, number of tillers per plant at genotypic level. Similar results were reported by Dencic *et al.* (2000) for canopy temperature. Chlorophyll content exhibited significant positive correlation with grain yield. Although chlorophyll content showed negative direct effect on grain yield but it was countered by indirect positive effect due to plant height, number of grain per ear, canopy temperature depression and number of days to fifty per cent flowering. Similar results were obtained by Xiao *et al.* (2012) for chlorophyll content. Flag leaf area showed positive direct effect on grain yield at genotypic level only. Similar finding were also reported by Nukasani *et al.* (2013) for number of tillers per plant, chlorophyll content and flag leaf area. Bhutta *et al.* (2006) also observed positive direct effect of flag leaf area on grain yield per plant. Relative water content, relative water loss, canopy temperature depression, and days to maturity showed positive indirect effect via canopy temperature at genotypic level. These result were in accordance with Anwar *et al.* (2009) for relative water loss and relative water content. Five character viz canopy temperature, chlorophyll content, tillers per plant, flag leaf area and days to maturity showed indirect positive effect via relative water loss. Similar results were reported by Ahmadizadeh *et al.* (2011), for chlorophyll content and flag leaf area. Plant height exhibited significant correlation with grain yield due to its positive direct effect with grain yield and indirect positive effect with number of grain per ear and relative water loss. Similar result were obtained by Kashif and Khaliq (2004). Therefore, canopy temperature, relative water loss, flag leaf area, chlorophyll content and tiller per plant should be given preference to increase the grain yield in bread wheat since correlation coefficient was also high and in the same direction as of direct effect with grain yield per plant, indicating their true relationship with grain yield per plant. The presence of high residual values both at

genotypic and phenotypic level indicated that the morphological and physiological traits selected in present study does not have significant effect on grain yield per plant.

5.5 Genetic divergence

Based on mahalanobis euclidean cluster analysis 32 genotypes were grouped into six clusters. Cluster 1 had maximum genotypes namely i.e twenty five (Cross 1 RIL 1, 2, 3, 4, 5, 6, 7, 8, 10. Cross 2 RIL 11, 12, 13, 14, 16, 17, 18, 19, 20, Cross 3 RIL 21, 22, 26, 27, 29 and check 1 i.e. HUW 234 showing less divergence between genotypes belonging to cluster I, followed by cluster fifth having three genotype (Cross 1 RIL 9, Cross 3 RIL 24, 28), second cluster having one genotype (Cross 3 RIL 25), third cluster also has one genotype (Cross 2 RIL 15), fourth cluster has Check 2 i.e. PBN 51 and cluster sixth (Cross 3 RIL 30) depicted in table 10. Hailegiorgis *et al.* (2011) on the basis of dendrogram grouped the 49 bread wheat genotypes into 22 different clusters with cluster 9 and 13 deserve for their direct use as parents in hybridization programs for the development of high yielding varieties. Dutamo *et al.* (2015) clustered 60 genotypes of bread wheat into six clusters. Kalimullah *et al.* (2012) distributed the 30 genotypes into 8 clusters and observed that the distribution pattern of genotype in different clusters was random. To get more heterotic and large number of desirable transgressive segregants, selection of parents for hybridization should be properly based on genetic diversity rather than geographic diversity.

The average intra cluster distance between the genotypes of cluster I was maximum followed in descending order by clusters V whereas cluster II, cluster III, Cluster IV, Cluster VI exhibited zero intra cluster distance because of only one genotype in their clusters. Intercluster studies showed that genotype of the cluster II and VI exhibited maximum divergence because of its high intercluster distance followed in descending order by the genotypes of cluster III and VI, VI and V, IV and VI, VI and I, II and IV, III and IV, V and IV, V and I indicating the chances of getting high yielding recombinant would be better if the crosses are made among the genotype of these groups. The minimum inter cluster distance was recorded between IV and I, II and I, I and III, II and V, III and V and II and III. These clusters showing lowest inter cluster distance were less divergent. Raj *et*

al., (2018) also identified most diverse cluster based on intra and inter cluster distance and suggested their use in hybridization programme for achieving high yielding varieties.

On the basis of cluster mean, flag leaf area and canopy temperature depression showed maximum values in cluster 1. Cluster II recorded maximum mean value for thousand grain weight, number of grains per ear and minimum values for number of days to maturity. Cluster IV recorded high mean value for tillers per plant, relative water content and grain per yeild whereas it recorded minimum mean value for relative water loss and canopy temperature. Cluster VI recorded minimum mean value for days to fifty per cent flowering. Similar findings were also observed by Garten *et al.* (2003), Dwivedi *et al.* (2005), Arya *et al.* (2017), and Naik *et al.* (2016).

The maximum contribution towards the total divergence as given in table (13) was exhibited by number of days to flowering, followed by relative water content, flag leaf area, days to maturity, chlorophyll content, grain yield per plant , tillers per plant, relative water loss. The trait viz number of days to fifty percent flowering, relative water content, flag leaf area, days to maturity, chlorophyll content and grain yield per plant contributed more than 70% towards divergence. Similar findings were also obtained by Dobariya *et al.* (2006) for days to fifty percent flowering, number of tillers per plant, days to maturity and thousand grain weight and Joshi *et al.* (2005) for days to fifty per cent flowering, plant height, thousand grain weight Hence, these characters should be given importance during hybridization and selection in process for improvement of yield and its component traits.

Chapter-6

Summary and Conclusion

CHAPTER-VI

SUMMARY AND CONCLUSION

The present investigation entitled as “**Genetic analysis of recombinant inbred lines for heat tolerance and productive trait in bread wheat (*Triticum aestivum* L.)**” was conducted to characterize elite recombinant inbred lines for morpho-physiological traits related to heat and productivity, to study the genetic divergence for heat tolerance in recombinant inbred line populations and to study the empirical association of heat traits in determining the grain yield. The experimental material for present study included thirty recombinant inbred lines of bread wheat derived from three crosses viz. LOK- 1 X HUW-468, LOK1 X HUW-234 and Raj-4014 X PBN-51 along with two checks PBN-51 and HUW-234.

The RILs along with two check parents were evaluated for genetic diversity at the Research Farm of Division of Plant Breeding and Genetics, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Main Campus, Chatha, Jammu during *Rabi* 2018-19. The experimental material was grown in a randomized block design with three replications. All the recommended Package of Practices were followed during crop growth. The data were recorded on various morphological and physiological traits viz number of days to fifty per cent flowering, number of days to maturity, plant height (cm), number of tillers per plant, ,number of grains per ear, thousand grain weight (g), flag leaf area (cm²), grain yield per plant (g), chlorophyll content (SPAD unit), relative leaf water content (%), relative water loss (%), canopy temperature (°C), and canopy temperature depression (°C).

The salient findings from the experiment are concluded below.

Analysis of variation (ANOVA) determined the significant variation in mean sum square of the genotypes for all the traits under study which revealed presence of significant genetic variation among the RILs population. This variability among the RILs made them good source for selecting superior and desired genotypes for further improvement.

Environmental influence was less on the expression of almost all the characters as it was evident by narrow gap between genotypic and phenotypic coefficient of variation. Moderate GCV and PCV was reported for canopy temperature, plant height, flag leaf area and thousand grain weight. Low GCV and PCV was reported for number of days to fifty per cent flowering, number of tillers per plant, number of days to maturity, number of grains per ear, grain yield per plant, chlorophyll content, relative leaf water content, canopy temperature depression, and relative water loss. It indicates that selection may be effective based on the characters such as canopy temperature, plant height, flag leaf area and thousand grain weight with high and medium Phenotypic Coefficients of Variation (PCV) and Genotypic Coefficients of Variation (GCV) values and their phenotypic expression would be a good indication of genetic potential.

High heritability and high genetic gain as percent of mean was reported for flag leaf area whereas high heritability and moderate genetic gain was reported for relative water content and number of days to fifty percent flowering. Moderate heritability and genetic gain was reported for canopy temperature, plant height, tillers per plant, grain weight and grain yield per plant indicating that simple selection scheme would be effective for these characters to bring genetic improvement in desired direction.

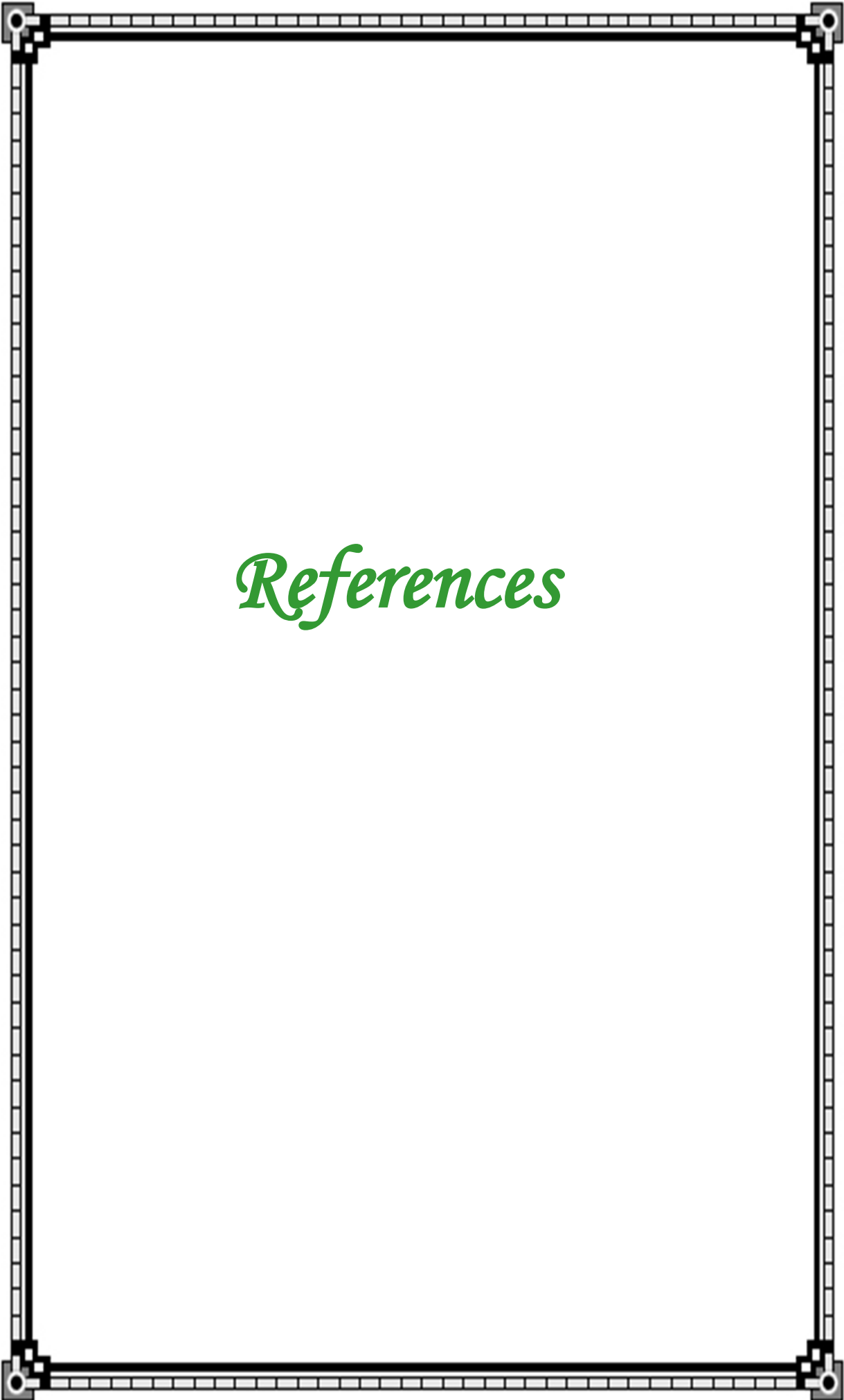
Grain yield per plant exhibited significant positive correlation with plant height, tiller per plant and chlorophyll content and positive correlation with flag leaf area whereas significant negative correlation with canopy temperature, relative water loss and canopy temperature depression at genotypic level. At phenotypic level grain yield per plant exhibited positive correlation with plant height, relative water content, chlorophyll content, flag leaf area. Thus, it can be concluded from the present study that plant height, tillers per plant, chlorophyll content, tillers per plant, flag leaf area, canopy temperature and canopy temperature depression can be used as indirect selection tools for breeding of high yield varieties of wheat under heat stress.

A critical perusal of path coefficient analysis in which diagonal values where direct effects revealed that, plant height, number days to maturity, days to fifty percent flowering had positive direct effect on grain yield per plant at both phenotypic and genotypic level. Chlorophyll content and tillers per plant showed positive direct effect with grain yield per

plant at phenotypic level. Flag leaf area showed positive direct effect on grain yield per plant at genotypic level. Hence selection for such traits would prove beneficial for getting heat tolerant recombinants and can be used as criteria during selection for grain yield under heat stress situation.

Based on Mahalanobis D^2 analysis, 32 genotypes were grouped into six clusters. This indicated that the presence of moderate diversity of genotypes. Genetic divergence studies suggested that Cluster 1 had maximum genotypes namely i.e twenty five followed by cluster fifth having three genotype, second cluster having one genotype, third cluster also has one genotype, fourth cluster with one genotype and cluster sixth also with one genotype. Cluster I had maximum genotype namely Cross 1 RIL 1, 2, 3, 4, 5, 6, 7, 8, 10. Cross 2 RIL 11, 12, 13, 14, 16, 17, 18, 19 and 20. Cross 3 RIL 21, 22, 26, 27, 29 and Check HUW 234 exhibiting less divergence among these genotypes. The maximum inter cluster distance was observed between genotype of the cluster II and VI exhibited maximum divergence followed in descending order by the genotypes of cluster III and VI, VI and V, IV and VI, VI and I, II and IV, III and IV, V and IV indicating the chances of getting high yielding recombinant would be better if the crosses are made among the genotype of these groups and thus may be utilized under inter varietal hybridization programme (transgressive breeding) for getting high yielding recombinant. The trait namely days to flowering, relative water content, flag leaf area, days to maturity, chlorophyll content and grain yield per plant contributed more than 70% towards divergence. Hence, these characters should be given importance during hybridization and selection in process for improvement of yield and its component traits. Cluster mean values showed that cluster IV showed low value of mean for canopy temperature and relative water loss whereas high value for number of tillers per plant, grain yield per plant, chlorophyll content and relative water content. Cluster II showed high values for thousand grain weight and number of grains per ear. The crossing between the entries belonging to cluster pairs possessing high cluster means for one or other trait to be improved may be recommended for isolating desirable recombinants in the segregating generations for heat tolerance. Chlorophyll content showed high value for PBN-51 followed by cross 2 RIL 15, Cross 3 RIL 23 and Cross 3 RIL 24, with nearly same values showing low chloroplast damage due to high temperature. For relative water content Cross 1 RIL 1 showed high value followed by Cross

1 RIL 4, Cross 3 RIL 29 showing better water status under dehydration. Relative water loss was lower at high temperature in PBN-51 followed by RIL 14 and 12 of cross 2 showing low water loss at high temperature. Low canopy temperature was exhibited by check HUW-234 followed by Cross 3 RIL 27, both having almost equal values indicating that they maintain cooler canopy conditions at high temperature.



References

REFERENCES

- Abinasa, M., Ayana, A. and Bultosa, G. 2011. Genetic variability, heritability and trait associations in durum wheat (*Triticum turgidum* L. var. durum) genotypes. *African Journal of Agricultural Research*, **6**(17): 3972-3979.
- Abou-Deif, M. H., & Mohamed, F. I. 2007. Effect of heat stress on chromosomes and protein patterns in six hexaploid wheat varieties. *Journal of Cellular and Molecular Biology*, **34**(6): 42-49.
- Agarwal, S., Sairam, R. K., Srivastava, G. C. And Meena, R. C. 2005. Changes in antioxidant enzymes activity and oxidative stress by abscisic acid and salicylic acid in wheat genotypes. *Biological Plantarum*, **49**(4): 541-550.
- Aharizad, S., Sabzi, M., Mohammadi, S. A. and Khodadadi, E. 2012. Multivariate analysis of genetic diversity in wheat (*Triticum aestivum* L.) recombinant inbred lines using agronomic traits. *Annals of Biological Research*, **3**(5): 2118-2126.
- Ahmadizadeh, M., Shahbazi, H., Valizadeh, M. and Zaefizadeh, M. 2011. Genetic diversity of durum wheat landraces using multivariate analysis under normal irrigation and drought stress conditions. *African Journal of Agricultural Research*, **6**(10): 2294-2302.
- Aldesuquy, H. Z. B. and Mickky, B. 2014. Kinetin and spermine mediated induction of salt tolerance in wheat plants: Leaf area, photosynthesis and chloroplast ultrastructure of flag leaf at ear emergence. *Egyptian Journal of Basic and Applied Sciences*, **11**(45): 77-87.
- Alexander, L. V., Peterson, T. C., Ceaser, J., Gleason, B., Tank, A., Haylock, M., Collins, D., Trewin, B., Rahimzahed, F., Tagipour, A., Kumar, K. R., Ravadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, and Vazquer-Agruirre, J.L. 2006. Global observed changes in daily Climate extremes of temperature and precipitation. *Journal of Geophysics Research Atmosphere*, **111**: 1-22.

- Ali, Y., Atta, B. M., Akhter, J., Monneveux, P. and Lateef, Z. 2008. Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. *Pakistan Journal of Botany*, **40**(5): 2087-2097.
- Al-Khatib, K. and Paulsen, G. M. 1990. Photosynthesis and productivity during high-temperature stress of wheat genotypes from major world regions. *Crop Science*, **30**(5): 1127-1132.
- Anwar, J., Ali, M. A., Hussian, M., Sabir, W., Khan, M. A., Zulkiffal, M. and Abdullah, M. 2009. Assessment of yield criteria in bread wheat through correlation and path analysis. *The Journal of Animal and Plant Science*, **19**(4): 185-188.
- Anonymous 2019a, Crop Production Summary 2019. USDA (United State Department of Agriculture)
- Anonymous 2019b, Anonymous (20018-2019). Project Director's Report Indian Institute of Wheat and Barley Research, ICAR, Karnal.
- Anonymous 2019c. Anonymous (20018-2019). Project Director's Report Indian Institute of Wheat and Barley Research, ICAR, Karnal.
- Arya, V. D., Pawar, I. S. and Lamba, R. A. S. 2005. "Genetic variability, correlation and Path analysis for yield and quality traits in bread wheat." *Haryana Agriculture University Journal of Research*, **35**(1): 59-63.
- Arya, V. K., Singh, J., Kumar, L., Kumar, R., Kumar, P. and Chand, P. 2017. Genetic variability and diversity analysis for yield and its components in wheat (*Triticum aestivum* L.). *Indian Journal of Agricultural Research*, **51**(2): 43-35
- Ayeneh, A., Van-Ginkel, M., Reynolds, M. P. and Ammar, K. 2002. Comparison of leaf, spike, peduncle, and canopy temperature depression in wheat under heat stress. *Field Crops Research*, **79**: 173-184.
- Balla, K., Karsai, L., Beneze, S, and Veisz, O. 2012. Germination ability and seedling vigour in the progeny of heat stressed wheat plant. *Journal of Acta Agronomica hungarica*, **60**(4); 299-308.

- Balota, M., Payne, W. A., Evett, S. R. and Lazar, M. D. 2007. Canopy temperature depression sampling to assess grain yield and genotypic differentiation in winter wheat. *Journal of Crop Science*, (47): 1518-1529.
- Balota, M., Peters, T. R., Payne, W. A. and Evett, S. R. 2018. Morphological and physiological traits related with canopy temperature depression in closely related wheat lines. *Crop Science*, 48(5): 1897-1910.
- Bandana, J., Shambhoo, P., Reena R., Singh, S., Kumar, A., Kumar, A. and Yadav, R. K. 2018. Evaluation of wheat line at reproductive stage for heat stress tolerance. *International Journal of Current Microbiology and Applied Sciences*, 7: 1350-1357.
- Batts, G. R., Ellis, R. H., Morison, J. I. L., Nkemka, P. N., Gregory, P. J., & Hadley, P. 1998. Yield and partitioning in crops of contrasting cultivars of winter wheat in response to CO₂ and temperature in field studies using temperature gradient tunnels. *The Journal of Agricultural Science*, 130(1):17-27.
- Bhushal, N. R., Sarial. D. A. 2016. *Genetic and molecular marker analysis for heat tolerance in wheat (Triticum aestivum L.)*. Ph.D. Thesis; CCS HAU Hisar.
- Bhushan, B., Bharti, S., Ojha, A., Pandey, M., Gourav, S. S., Tyagi, B. S. and Singh, G. 2013. Genetic variability, correlation coefficient and path analysis of some quantitative traits in bread wheat. *Journal of Wheat Research*, 5(1): 21-26.
- Bhutta, W. M. 2006. Role of some agronomic traits for grain yield production in wheat (*Triticum aestivum* L.) genotypes under drought conditions. *Revista UDO Agrícola*, 6(1): 11-19.
- Blum, A., Klueva, N. and Nguyen H. T. 2001. Wheat cellular thermotolerance is related to yield under heat stress. *Euphytica* 117(2): 117-123.
- Burton, G. W. 1952. Quantitative inheritance of grasses. Proceeding of 6th International, Grassland Congress. 1: 277-283.
- Chen, X., Sun, Q. And Sun, C. 2000. Performance and evaluation of spring wheat heat tolerance. *Journal of China Agricultural University*, 5(1): 43-49.

- Dencic, S., Kastori, R., Kobiljski, B., & Duggan, B. 2000. Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. *Euphytica*, **113**(1) : 43-52.
- Desheva, G. and Kyosev, B. 2015. Genetic diversity assessment of common winter wheat (*Triticum aestivum* L.) genotypes. *Journal of Food and Agriculture*, **27**(3): 283-290.
- Dewey, R. and Lu, K. H. 1959. A correlation and path coefficient analysis of crested wheat grass seed production. *Agronomy Journal*, **51**: 515-518.
- Dobariya, K. L., Ribadia, K. H., Padhar, P. R. and Ponkia, H. P. 2006. Analysis of genetic divergence in some synthetic lines of breadwheat (*Triticum aestivum* L.). *Advances in Plant Sciences*. **19**(1): 221-225.
- Dutamo, D., Alamerew, S., Eticha, F. and Assefa, E. 2015. Genetic Variability in Bread Wheat (*Triticum aestivum* L.) Germplasm for yield and yield Component Traits. *Journal of Biology, Agriculture and Healthcare*, **5**:140-147.
- Dwivedi, A. N. and Pawar, I. S. 2005. Evaluation of genetic diversity among wheat germplasm lines for yield and quality attributing traits in bread wheat. *Haryana Agriculture university Journal of Research*, **34**(1): 35-39.
- Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A. and Ihsan, M. Z. 2017. Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, **8**: 1147.
- FAO. 2018 *World Food and Agriculture*. Statistical Yearbook. Food and Agriculture Organization of the United States, Rome.
- Farooq, M., Bramley, H., Palta, J. A. and Siddique, K. H. M. 2011. Heat Stress in Wheat during Reproductive and Grain-Filling Phases. *Critical Reviews in Plant Sciences*, **30**: 1-17.
- Fischer, R. A. and Reynolds, M. P. 1996. Canopy temperature depression association with yield of irrigated spring wheat cultivars in a hot climate. *Journal of Agronomy and Crop Science*, **176**(2): 119-129.

- Fisher, R. A. and Byerlee, D. 1991. Trends of wheat production in the warmer areas: major issues and economic considerations. In 3. *International Conference on Wheat for the Nontraditional Warm Areas, Foz do Iguacu (Brazil), 29 Jul-3 Aug 1990*. CIMMYT.
- Fu, Y. and Somers, D. 2009 Genome wide reduction of Genetic Diversity in Wheat Breeding *Crop Science*, **49**: 161-168.
- Garten, S. L. and Mittal, R. K. 2003. Genetic divergence in bread wheat. *Crop improvement*, **30**(2):185:188.
- Gibson, L. R., and Paulsen, G. M. 1999. Yield components of wheat grown under high temperature stress during reproductive growth. *Crop Science*, **39**(6): 1841-1846.
- Gill, B., Appels, R. A., Botha-Oberholster, C., Buell, J. and Bennetzen, B. C. 2004. Workshop report on wheat genome sequencing. *International genome research on wheat consortium*, **168**: 1087-1096.
- Gulnaz, S., Khan, S. H., Shahzad, M., Ashfaq, M. and Sajjad, M. 2012. Genetic Evaluation of Spring Wheat (*Triticum aestivum* L.) Germplasm for yield and seedling vigour traits. *Journal of Agriculture & Social Sciences*, **8**: 123 128.
- Gupta, M. 2014. *Genetic analysis of terminal heat tolerance in wheat using molecular markers*. (Doctoral dissertation, CCSHAU)
- Hailegiorgis, D., Mesfin, M. and Genet, T. 2011. Genetic Divergence Analysis on some Bread Wheat Genotypes Grown in Ethiopia. *Journal of Central European Agriculture*, **12**(2): 344-352.
- Halford, N.G. 2009. New insight on the effect of heat stress on crop. *Journal of Experimental Botany*, **60**: 4215-4216.
- Hansen, J., Sato, M.K. and Ruedy, R. 2012. Precipitation of climate change. *Proceeding of the National Academy of Science*, **109**(2): 14726-14727.
- Hennessy, K., Fawett, R., Kirono, D., Mpelalasoka, F., Jonesd., Bathols, J., Whetton, P., Stafford Smith, M., Howden, M., Mitchell, C. and Plummer, N. 2008. An

assessment of the impact of climatic change on the nature and frequency of exceptional climatic event. *CSIRO and Bureau of Meteorology*, <http://www.daff.gov.au/pdf/file/0007/721285/csirobom-report-future-drought.pdf>.

- Hassan, M. I., Mohamed, E. A., El-rawy, M. A. and Amein, K. A. 2016. Evaluating interspecific wheat hybrids based on heat and drought stress tolerance. *Journal of crop science and biotechnology*, **19**(1): 85-98.
- Hays, D. B., Do, J. H., Mason, R. E., Morgan, G. and Finlayson, S. A. 2007. Heat stress induced ethylene production in developing wheat grains induces kernel abortion and increased maturation in a susceptible cultivar. *Plant Science*, **172**(6): 1113-1123.
- Jaiswal, J. P., Bhowmick, P. K. and Grover, A. 2010. Selection of bread wheat genotypes for heat tolerance based on physiological traits and heat shock proteins. *Journal of crop science and biotechnology*, **32**(1): 67-89.
- Jeena, A. S. and Upreti, M. C. 2004. Pattern of genetic diversity in wheat. *Environment and Ecology*, **22**(4): 899-902.
- Johnson, H. W., Robinson, H. F. and Comstock, R. 1955. Estimates of genetic and environmental variability in soybeans. *Agronomy Journal*, **47**(7): 314-318.
- Joshi, A. K., Chand, R., Arun, B., Singh, R. P. and Ortiz, R. 2007. Breeding crops for reduced-tillage management in the intensive rice-wheat systems of South Asia. *Euphytica*, **153**: 135-151.
- Joshi, A. K., Mishra, B., Chatrath, R., Ferrara, G. O. and Singh, R. P. 2005. Wheat improvement in India: present status, emerging challenges and future prospects. *Euphytica*, **157**(3): 431-446.
- Kaddem, W. K., Marke, Lavanya, G. R. 2014. Investigation of genetic variability and correlation analysis of wheat (*Triticum aestivum* L.) genotypes for grain yield and its Component traits. *European Academic Research*, **2**(5): 6529-6538.

- Kajla, M., Yadav, V. K., Khokhar, J., Singh, S., Chhokar, R. S., Meena, R. P., & Sharma, R. K. 2015. Increase in wheat production through management of abiotic stresses a review. *Journal of Applied and Natural Science*, **7**(2):1070-1080.
- Kalimullah, S. J., Khan, J. and Hu, R. 2012. Genetic variability, correlation and diversity studies in bread wheat (*Triticum aestivum* L.) germplasm. *Journal of Animal and Plant Science*, **22**(2): 330-33.
- Kaur, V., Madaan, S. and Behl, R. K. 2017. ADP-glucose pyrophosphorylase activity in relation to yield potential of wheat: response to independent and combined high temperature and drought stress. *Cereal Research Communications*, **45**(2): 181-191.
- Khan, A. A., Barma, N. C. D., Hasan, M. M., Alam, A. and Alam, M. K. 2014. Correlation study on some heat tolerant traits of spring wheat (*Triticum aestivum* L.) under late sowing conditions. *Journal of Agricultural Research*, **52**(1): 11-23.
- Kashif, M., and I. Khaliq. 2004. Heritability, correlation and path coefficient analysis for some metric traits in wheat. *International Journal of Agriculture Biology* **34**(6):138–142.
- Khazaei, H., Monneveux, P., Hongbo, S., & Mohammady, S. 2010. Variation for stomatal characteristics and water use efficiency among diploid, tetraploid and hexaploid Iranian wheat landraces. *Genetic Resources and Crop Evolution*, **57**(2): 307-314.
- Krishna, K. S. and Jai, P. S. 2018. Canopy temperature depression and stay green: Major components for identifying terminal heat stress resistant genotypes of wheat. *International Journal of pure and applied Bioscience*, **6**(3): 374-381.
- Kumar, B., Lal, G. M. and Upadhyay, A. 2009. Genetic variability, diversity and association of quantitative traits with grain yield in bread wheat (*Triticum aestivum* L.). *Asian Journal of Agricultural Sciences*, **1**(1): 4-6.
- Kumar, A., Sirohi, A. and Kumar, S. 2013. Studies of selection parameter in common bread wheat (*Triticum aestivum* L.). *International Journal of Engineering & Science Research*, **2**: 90-94.

- Kumar, A., Ram, R. B., Singh, S. P. and Kumar, A. 2012. Studies on yield and its component traits in bread wheat (*Triticum aestivum* L.). *New Botanist*, **29**(14): 175-180.
- Kyosev, B. and Desheva, G. 2015. Study on variability, heritability, genetic advance and associations among characters in emmer wheat genotypes (*Triticum dicoccon* Schrank). *Journal of Biomedical Science and Biotechnology*, **8**(2): 221-228.
- Li, Y., Zhang, W., Ma, L., Wu, L., Shen, J., Davies, W. J. and Dou, Z. 2014. An analysis of China's grain production: looking back and looking forward. *Food and Energy Security*, **3**(1): 19-32.
- Lobell, D. B., Schlenker, W. and Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. *Crop Science*, **333**: 616-620.
- Lush, J. L. 1940. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. *Journal of Animal Science*, **1940**(1): 293-301.
- Mahato Chandrashekhar and V. Kerketta. 2004. Estimation of some genetic parameters under normal and late sown conditions in wheat (*Triticum aestivum* L.). *Journal of Agriculture Research*, **16** (1):119-121.
- Majumder, D. A. N., Shamsuddin, A. K. M., Kabir, M. A. and Hassan, L. 2008. Genetic variability correlated response and path analysis of yield and yield contributing traits of spring wheat. *Journal of Bangladesh Agriculture University*, **6**(2): 227-234.
- Mason, R. E., Mondal, S., Beecher, F. W., Pacheco, A., Jampala, B., Ibrahim, A. M. and Hays, D. B. 2010. QTL associated with heat susceptibility index in wheat (*Triticum aestivum* L.) under short-term reproductive stage heat stress. *Euphytica*, **174**(3): 423-436.
- Maurya, B. R. and Raghuwanshi, R. 2014. Isolation and characterization of PGPR and their effect on growth, yield and nutrient content in wheat (*Triticum aestivum* L.). *Biocatalysis and Agricultural Biotechnology*, **3**(4): 121-128.

- Modarresi, M., Mohammadi, V., Zali, A. and Mardi, M. 2011. Response of wheat yield and yield related traits to high temperature. *Cereal Research Communications*, **38**(1): 23-31.
- Mohammadi, V., Canada, M. R., Sail, A. A. and Yazdi, S. B. 2004. Effects of post-anthesis heat stress on the heat traits of wheat. *International Journal of Agriculture and Biology*, **6**(1): 42-44.
- Moyghaddam, M., Ehdie, B. and Waines, J. G. 1998. Genetic variation for and inter-relationships among agronomic traits in landraces of bread wheat from south western Iran. *Journal of Genetics and Breeding*, **52**(91): 73-81.
- Munjal, R. and Dhanda, S. S. 2004. Associations for heat tolerance in bread wheat. *National Journal of Plant Improvement*, **6**(1): 71-73.
- Munjal, R. and Rana, R. K. 2003. Evaluation of physiological traits in wheat (*Triticum aestivum* L.) for terminal high temperature tolerance. *Proceedings of the Tenth International Wheat Genetics Symposium, Classical and Molecular Breeding*, Poestum, Italy, **2**: 804-805.
- Murthy, M. N. 1967. Sampling theory and methods. *Sampling theory and methods. Australian Journal of Crop Science*, **9**(7):67
- Naik, V. R., Biradar, S. S., Hanchinal, R. R., Desai, S. A. and Veeresha, B. A. 2016. Correlation and path analysis for yield and some morpho-physiological characters in tetraploid wheat under irrigated and rainfed conditions. *Research in Environment and Life Sciences*, **9**(2): 206-209.
- Nukasani, V., Potdukhe, N. R., Bharad, S., Deshmukh, S. and Shinde, S. M. 2013. Genetic variability, correlation and path analysis in wheat. *Journal of Wheat Research*, **5**(2): 48-51.
- Olivares-Villegas, J. J., Reynolds, M. P. and McDonald, G. K. 2007. Drought adaptive attributes in the Seri/Babax hexaploid wheat population. *Functional Plant Biology*, **34**: 189-203.

- Orth, R. A. and Shellenberger, J. A. 1988. Origin, Production and Utilization of wheat. In Pomeranz, Y. Wheat Chemistry and Technology. American Association of Cereal Chemists, Minnesota. *Journal of Cereal Science*, **45**: 1-14.
- Ortiz, R., Sayre, K. D., Govaerts, B., Gupta, R., Subbarao, G. V., Ban, T. and Reynolds, M. 2008. Climate change and its effect on wheat. *Agriculture, Ecosystems & Environment*, **126**(1-2): 46-58.
- Palwal, R., Röder, M. S., Kumar, U., Srivastava, J. P., & Joshi, A. K. 1994. QTL mapping of terminal heat tolerance in hexaploid wheat (*T. aestivum* L.). *Theoretical and Applied Genetics*, **125**(3) : 561-575.
- Pandey, G. C., Mamrutha, H. M., Tiwari, R., Sareen, S., Bhatia, S., Siwach, P. and Sharma, I. 2015. Physiological traits associated with heat tolerance in bread wheat (*Triticum aestivum* L.). *Physiology and Molecular Biology of Plants*, **21**(1): 93-99.
- Pandey, I. B., Pandey, R. K., Dwivedi, D. K. and Singh, R. S. 2010. Phenology, heat unit requirement and yield of wheat (*Triticum aestivum* L.) varieties under different crop-growing environment. *Indian Journal of Agricultural Sciences*, **80**(2): 136-140.
- Palve, S.M. and P. Raghavaiah. 2002. Genetic variation and interrelationship of agronomic traits in interspecific derivatives of durum wheat (*Triticum aestivum* L.). *Annals of Agricultural Research*, **23** (4): 602-607.
- Panse, V. G. 1984. Genetics of quantitative characters in relation to plant breeding. *Indian Journal of Genetics*, **17**: 318-328.
- Patil, K. S., Durge, D. V. and Shivankar, R. S. 2003. Effect of temperature on yield and yield components of early wheat cultivars. *Journal of Maharashtra Agricultural Universities, College of Agriculture*, **28**(1): 34-36.
- Pittock, B. 2003. Australian Guide to the Science and Potential of Impacts. *Functional Plant Biology*, **76**(23): 56-98.

- Prasad, P. V. V., Pisipati, S. R., Momcilovic, I. and Ristic, Z. 2011. Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast ef-tu expression in spring wheat. *Journal of Agronomy and Crop Science*, **197**: 430–441.
- Prakash, P., Sharma-Natu, P., Ghildiyal, M.C, 2003. High temperature effect on starch synthase activity in relation to grain growth in wheat cultivars.-Indian J. Plant Physiol. (Special Issue) **8**: 390–398.
- Priya, B., Mukherjee, S., Das, B., Satyanarayana, N. H., Sarkar, K. K., Uikey, B. L. Punia, S. S., Shah, M. and Ranwha, B. R. 2013. Genetic analysis for high temperature tolerance in wheat. *African Crop Science Journal*, **19**(3): 146–163.
- Rad, M. N., Kadir, M. A., Rafii, M. Y., Jaafar, H. Z., Naghavi, M. R., & Ahmadi, F. 2013. Genotype environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum* L.) under normal and drought stress conditions. *Australian Journal of Crop Science*, **7**(7): 956.
- Rahman, M., Barma, N. C. D., Biswas, B. K., Khan, A. A. and Rahman, J. 2016. Study on morphophysiological traits in spring wheat (*Triticum aestivum* L.) under rainfed condition. *Bangladesh Journal of Agriculture Research*, **41**(2): 235-250.
- Rahman, S., Shaheen, M. S., Rahman, M. and Malik, T. A. 2000. Evaluation of excised leaf water loss and relative water content as screening techniques for breeding drought resistant wheat. *Pakistan Journal of Biological Science*, **3**(4): 663-665.
- Rajaram, S., & Braun, H. J, 2008. Wheat yield potential. In *International Symposium on Wheat Yield Potential: Challenges to International Wheat Breeding*. CIMMYT. México, DF (pp. 103-107).
- Raj, N. 2018. *Diversity of bread wheat (Triticum aestivum L.) under terminal heat stress condition and their molecular characterization* (Doctoral dissertation, Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur).
- Rane, J., Shoran, J. and Nagarajan, S. 2000. Heat stress environments and impact on wheat productivity in India, *Indian Wheat News letter*, **6**(1): 5-6.

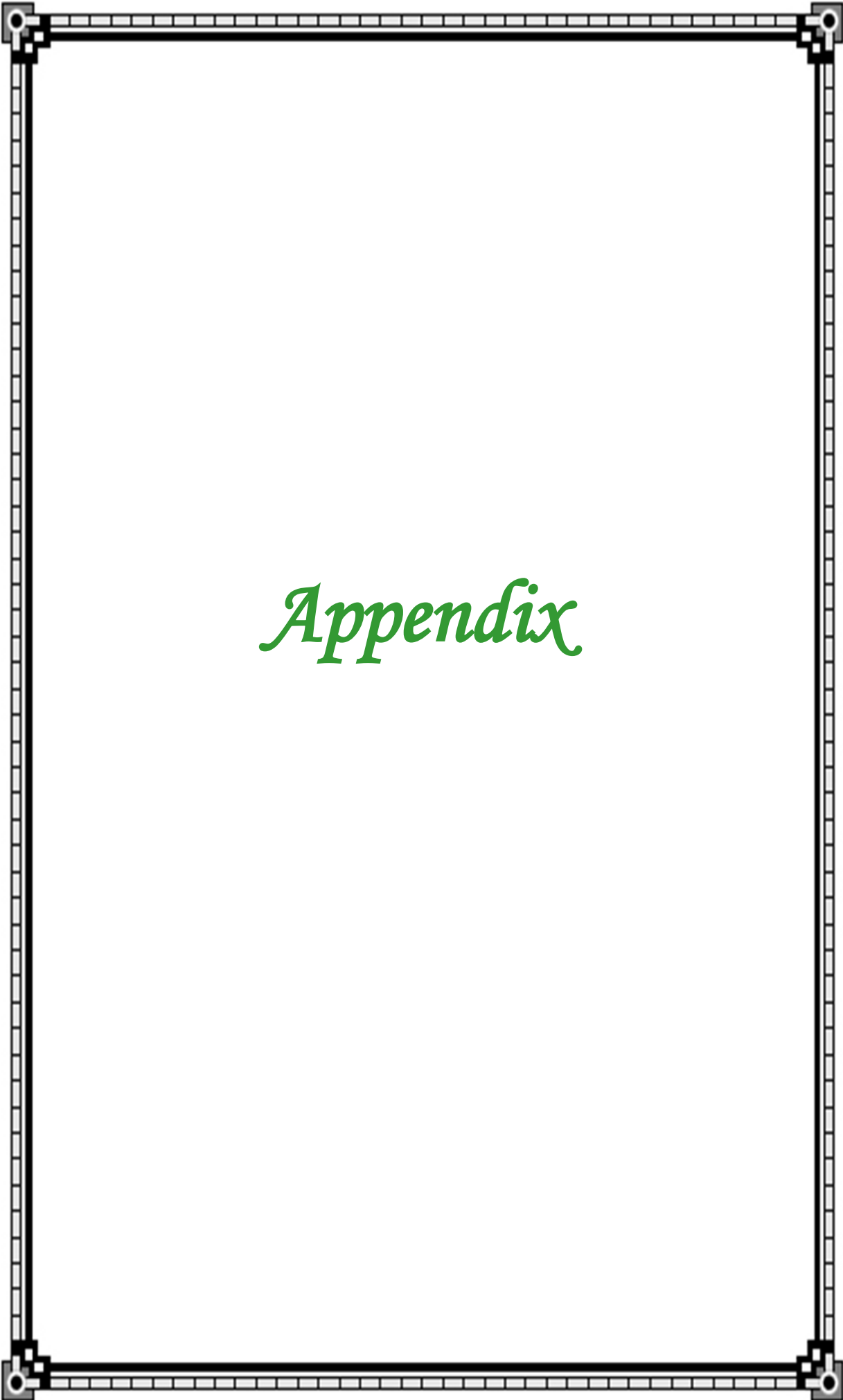
- Rao, C. R. 1952. Advanced statistical methods in biometric research. A Division of Macmillan Publishing Co, Inc New York; Collier-Macmillan Publishers; London.
- Reynolds, M. P., Singh, R. P., Ibrahim, A., Agerb, O. A. A., Larque-Saavedra A., Quick, J. S. and Braun, H. J. 2001. Evaluating physiological traits to complement empirical selection for wheat in warm environments. *Proceedings of the 5th International Wheat Conference, Turkey*, **10**: 143-152.
- Reynolds, M. P., Balota, M., Delgado, M. I. B., Amani, I. and Fischer, R. A. 1997. Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Functional Plant Biology*, **21**(6): 717-730.
- Ristic, Z., Bukovnik, U., Momcilovic, I., Fu, J. and Prasad, P. V. 2008. Heat-induced accumulation of chloroplast protein synthesis elongation factor, EF-Tu, in winter wheat. *Journal of plant physiology*, **165**(2): 192-202.
- Royo, C., Abaza, M., Blanco, R., and Moral, L. F. G. 2000. Triticale grain growth and morphometry as affected by drought stress, late sowing and simulated drought stress. *Functional Plant Biology*, **27**(11): 1051-1059.
- Sandeep, K., Mahendra, S. and Verma, R. S. 2000. Studies on heat tolerance in wheat genotypes. *Gujarat Agricultural University Research Journal*, **26**(1): 16-22.
- Sarkar, C. K. G., Srivastava, P. S. L. and Deshmukh, P. S. 2001. Grain growth rate and heat susceptibility index: traits for breeding genotypes tolerant to terminal high temperatures stress in bread wheat (*Triticum aestivum* L.). *Indian Journal of Genetics and Plant Breeding*, **61**(3): 209-212.
- Searle, S. R. 1961. Phenotypic genetic and environmental and correlation. *Biometrics*, **17**(3): 474-480.
- Shahidullah, S. M., Saha, A., Muttaleb, M. A., Aditya, T. L., Ali, M. A., & Kabir, M. S. 2017. Distribution of Crops and Cropping Patterns in Bangladesh. *Bangladesh Rice Journal of Crop Science*, **21**(2): 1-55.

- Shanahan, M. M., Quick, J. S., & J. F., 1990. Heat tolerance in winter wheat: II. Membrane thermostability and field performance. *Crop Science*, **30**(6):1248-1251.
- Shahid, M., Mohammad, F. and Tahir, M. 2002. Path coefficient analysis in wheat. *Sarhad Journal of Agriculture*, **18**(4): 383-388.
- Shankarrao, B. S., Mukherjee, S., Pal, A. K. and De, D. K. 2010. Estimation of variability for yield parameters in Bread Wheat (*Triticum aestivum* L.) grown in Gangetic West Bengal. *Electronic Journal of Plant Breeding*, **1**(4): 764-768.
- Sharma, B. R., Sumesh, K. V., Lohot, V. D. and Ghildiyal, M. C. 2006. High temperature effect on grain growth in wheat cultivars: An evaluation of responses. *Indian Journal of Plant Physiology*, **11**(3): 239.
- Sharma, V. and Pawar, I. S. 2010. Genetic divergence for yield, its components and quality traits in bread wheat. *Haryana agriculture University Journal of Research*, **37**: 27-31.
- Shewry PR, 2009. The Health grain programme opens new opportunities for improving wheat for nutrition and health. *Nutrition Bulletin*, **34**(2): 225–231.
- Shukla, R. S., Mishra, Y. and Rawat, G. S. 2001. Genetic analysis for screening of high temperature and moisture stress tolerance attributes in wheat (*Triticum aestivum* L.). *Crop Research*, **22**(1): 63-67.
- Sikder, S., Ahmed, J. U. and Hossain, T. 2001. Heat tolerance and relative yield performance of wheat varieties under late seeded conditions. *Indian Journal of Agricultural Research*, **35**(3): 141-148.
- Sivasubramanian J and Madhavamenon P. 1973. Genotypic and phenotypic variability in rice. *Madras Agriculture Journal* **12**: 15-16.
- Singh, P., Bhowmick, J. and Chaudhuri, B. K. 2006. Effect of temperature on yield and yield components of fourteen wheat (*Triticum aestivum* L.) genotypes. *Environment and Ecology*, **24**(3): 550-554.

- Singh, S. K. 2016. *Studies on genetic diversity among genotypes of bread wheat (Triticum aestivum L.)* (Doctoral dissertation, Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur).
- Singh, Swarnkar, G. B., Prasad, L., Singh, M. and Prasad, L. 2005. Genetic variability and path coefficient analysis in advanced generations of bread wheat under rainfed conditions. *Plant Archives*, **3**(1): 89-92.
- Singh, G., Tyagi, B. S., Singh, M. K., Bind, D., Saharan, M. S., Verma, A. and Sharma, I. 2003. Genetic analysis for economic traits in elite indigenous and exotic lines of bread wheat (*Triticum aestivum* L.) under timely sown high fertility conditions. *Journal of Wheat Research*, **4**: 45-48.
- Stone, P. J. and Nicolas, M. E. 1996. Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. II. Fractional protein accumulation. *Functional Plant Biology*, **23**(6): 739-749.
- Sukumaran, S., Dreisigacker, S., Lopes, M., Chavez, P., & Reynolds, M. P. 2015. Genome-wide association study for grain yield and related traits in an elite spring wheat population grown in temperate irrigated environments. *Theoretical and applied genetics*, **128**(2): 353-363.
- Sunita, Munjal, R., Ram K., Kumar, N., and Dhanda, S. S. 2017. Heat Stress Implications on Yield and Yield Component in recombinant inbred lines of Bread Wheat at Reproductive Stage. *International Journal of Pure and Applied Bioscience*, **5**(3): 1001-1007.
- Tandon, J. P. 1994. Wheat cultivation, research organization and production technology in the hot dry regions of India. Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems, 17-23.
- Uddin, M. J., Mitra, B., Chowdhury, M. A. Z. and Mitra, B. 1997. Genetic parameters, correlation, path coefficient analysis and selection indices in wheat. *Bangladesh Journal of Scientific and Industrial Research*, **32**(4): 523-528.

- Uddling, J., Gelang-Alfredsson, J., Piikki, K., & Pleijel, H. 2007. Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis research*, **91**(1):37-46.
- Verma, P., Yadav, A. N., Kazy, S. K., Saxena, A. K. and Suman, A. 2014. Evaluating the diversity and phylogeny of plant growth promoting bacteria associated with wheat (*Triticum aestivum* L.) growing in central zone of India. *International Journal of Microbiological and Applied Science*, **3**(5): 432-447.
- Wahid, A., Gelani, S., Ashraf, M. and Foolad, M. R. 2007. Heat tolerance in plants: an overview. *Environment and Experimental Botany*, **61**: 199–223.
- Wang, Y., Cheng, X., Shan, Q., Zhang, Y., Liu, J., Gao, C. and Qiu, J. L. 2014. Simultaneous editing of three homoeoalleles in hexaploid bread wheat confers heritable resistance to powdery mildew. *Nature biotechnology*, **32**(9): 947.
- Wani, B. A., Ram, M., Yasin, A. and Singh, E. 2011. Physiological traits in integration with yield and yield components in wheat (*Triticum aestivum* L.) study of their genetic variability and correlation. *Asian Journal of Agriculture Research*, **5**: 194-200.
- Wardlaw, I. F., Dawson, I. A., Munibi, P. and Fewster, R. 1989. The tolerance of wheat to high temperatures during reproductive growth, II. Survey procedures and general response patterns. *Australian Journal of Agricultural Research*, **40**: 1-13.
- Wright, S. 1921. Correlation and causation. *Journal of Agricultural Research*, **20**: 557-585.
- Wollenweber, B., Porter, J. R., & Schellberg, J. 2003. Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. *Journal of Agronomy and Crop Science*, **189**(3):142-150.
- Xiao, Y. G., Qian, Z. G., Wu, K., Liu, J. J., Xia, X. C., Ji, W. Q. and He, Z. H. 2012. Genetic gains in grain yield and physiological traits of winter wheat in Shandong Province, China, from 1969 to 2006. *Crop Science*, **52**(1): 44-56.
- Xue, Q., Zhu, Z., Musick, J. T., Stewart, B. A. and Dusek, D. A. 2006. Physiological mechanisms contributing to the increased water-use efficiency in winter wheat under deficit irrigation. *Journal of plant physiology*, **163**(2): 154-164.

- Yadav, S. K., Singh, A. K., Baghel, S. S., Jarman, M. and Singh, A. K. 2014. Traits among CIMMYT based wheat germplasm. *Journal of Wheat Research*, **6**(2): 123-156.
- Zarei, L., Cheghamirza, K., & Farshadfar, E. 2013. Evaluation of grain yield and some agronomic characters in durum wheat (*Triticum aestivum* L.) Under rainfed conditions. *Australian Journal of Crop Science*, **7**(5): 609.
- Zahedi, M. and Jenner, C. F. 2003. Analysis of the effects of high temperature on the grain filling attributes of wheat estimated from mathematical models of grain filling. *Journal of Agriculture Science*, **141**(2): 203-212.

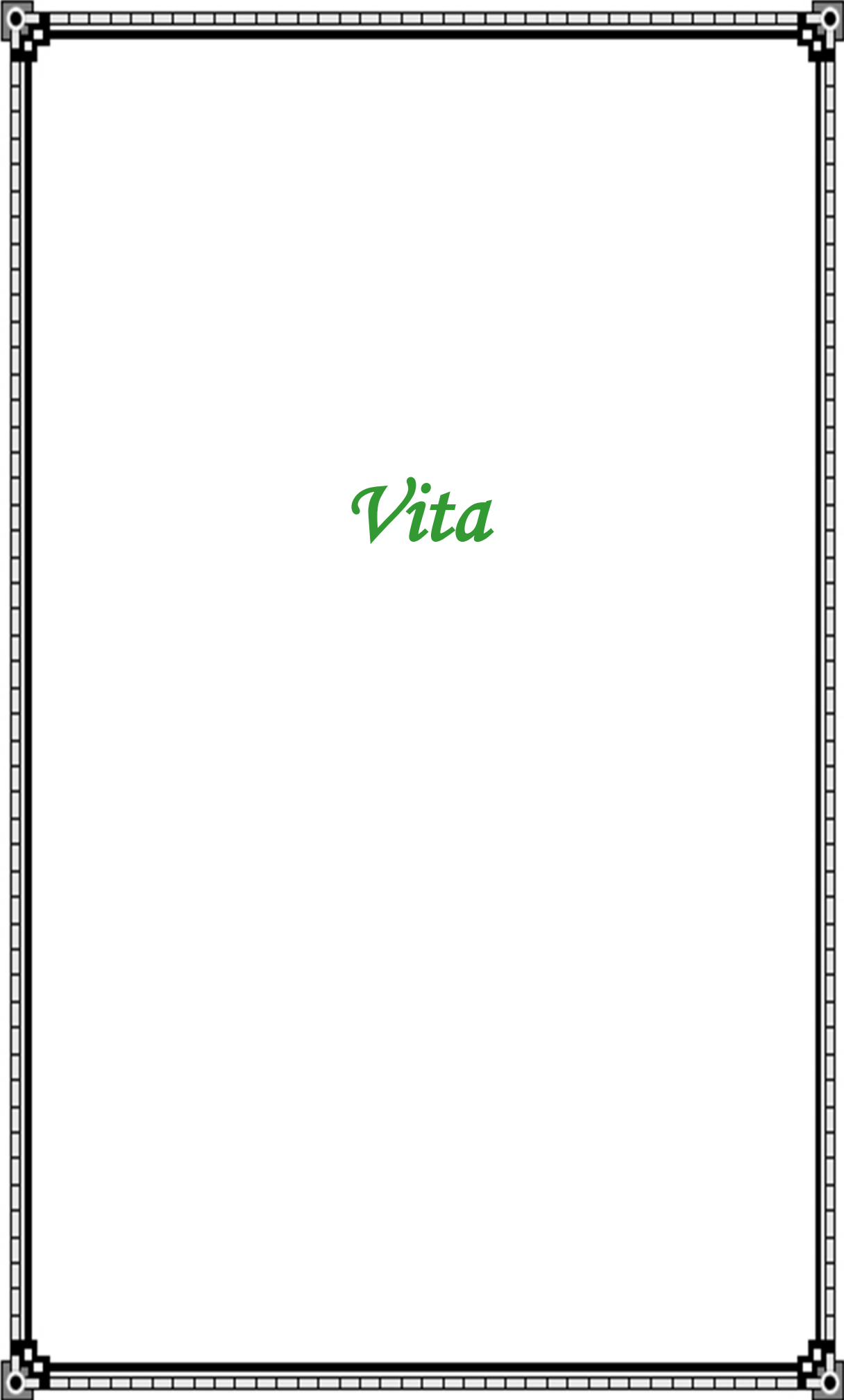


Appendix

APPENDIX – I

WEEKLY MET DATA FOR THE MONTH NOV. 2018 TO MAY 2019

Week	Temperature (°C)		Relative Humidity (%)		Wind speed (km/hr)	Rainfall (mm)
	Max	Min	Rh1	Rh2		
2018						
October 29	27.9	14.8	89	49	3.2	14.0
November 5	26.1	10.0	93	45	1.5	0.0
November 12	23.9	9.3	90	47	2.4	0.8
November 19	26.6	8.5	94	36	1.3	0.0
November 26	24.5	9.0	95	44	1.0	0.0
December 3	21.7	6.2	95	49	1.1	0.0
December 10	19.3	6.5	94	53	4.0	11.8
December 17	20.7	2.9	94	39	1.3	0.0
December 24	18.8	1.7	95	39	1.6	0.0
2019						
December 31	17.6	5.4	93.3	50.4	2.8	11.0
January 7	18.2	5.2	92.4	49.9	2.5	5.2
January 14	17.4	5.4	91.7	64.4	2.9	5.4
January 21	16.6	4.4	93.4	53.4	3.8	41.6
January 28	18.3	6.0	90.4	55.4	3.0	8.8
February 4	18.4	8.0	91.3	57.0	3.8	59.2
February 11	19.2	9.4	93.6	65.9	2.8	20.6
February 18	20.3	8.6	91.3	58.6	3.6	67.8
February 25	18.0	3.3	92.3	56.6	3.1	11.2
March 4	22.4	8.8	91.1	49.0	3.1	0.0
March 11	24.3	9.1	91.3	46.1	2.7	10.8
March 18	25.2	10.9	91.9	51.6	3.2	14.2
March 25	29.1	13.5	89.0	44.4	2.7	2.0
April 1	33.4	15.9	80.9	37.1	2.6	0.0
April 8	33.8	17.8	81.4	38.7	2.7	7.2
April 15	30.2	17.1	77.1	43.4	3.9	26.8
April 22	37.1	17.9	57.6	22.9	4.7	8.4
April 29	36.6	18.3	42.4	18.7	6.6	0.0
May 6	38.5	19.6	47.9	23.9	4.9	0.0
May 13	34.9	20.9	58.6	32.0	4.8	0.6
May 20	37.1	21.1	58.3	28.6	5.0	5.0
May 27	43.1	21.7	46.4	24.6	3.9	0.0



Vita

CURRICULUM VITA

Name of the Student : Harpreet Singh

Father's Name : Iqbal Singh

Mother's Name : Usha Kour

Nationality : Indian

Permanent Home Address : R/o House No.2 Chinar Colony, Jawarnagar,
Srinagar, Jammu and Kashmir.

EDUCATIONAL QUALIFICATION

Bachelor's Degree : B.Sc. Agriculture

University : SKUAST-Jammu, 2017

OGPA : 6.7/10

Master's Degree : M. Sc. (Plant Breeding and Genetics)

University : SKUAST-Jammu,

OGPA : 7.03/10

Title of Thesis : **Genetic Analysis of Recombinant Inbred
Line for Heat Tolerance and Productive
Trait in Bread Wheat (*Triticum aestivum* L.)**

CERTIFICATE-IV

Certified that the necessary corrections as suggested by the external examiner and the advisory committee have been duly incorporated in the thesis entitled "**Genetic Analysis of Recombinant Inbred Line for Heat Tolerance and Productive Trait in Bread Wheat (*Triticum aestivum* L.)**" submitted by **Harpreet Singh**, Registration number **J-17-M-505**.


Dr. Bikram Singh
Professor
Major Advisor

Place: Jammu

Date: 10-10-2019


Head
11/10/19
Prof. J. Chatha-180 001
Division of Plant Breeding and Genetics