

Genetic Studies of Wheat Genotypes under Restricted Irrigated Condition

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By

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2017

CERTIFICATE – I

*This is to certify that the thesis entitled “**Genetic studies of Wheat Genotypes under Restricted Irrigated condition**” submitted in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (Agriculture)** in the department of **Plant Breeding and Genetics** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Rana Saha** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.*

All the assistance and help received during the course of the investigation has been acknowledged by him.

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I, **Rana Saha S/o Shri ShibSankar Saha** certify the work embodied in thesis entitled “**Genetic Studies of Wheat Genotypes under Restricted Irrigated Condition**” is my own first hand bonafide work carried out by me under the guidance of **Dr. R.S.Shukla**, at Department of Plant Breeding and Genetics, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur M.P. during 2015 -16.

The matter embodied in the thesis has not been submitted for the award of any other degree / diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes and errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given, thereof.

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ABBREVIATION

%	-	Percentage
$\sqrt{\quad}$	-	square root
Σ	-	Summation
σ	-	Sigma
't' test	-	student 't' test
cm	-	Centimeter
df	-	degree of freedom
<i>et al.</i> ,	-	and others
g	-	Gram
SE	-	standard error
S.V.	-	sources of variations
S.S.	-	sums of squares
M.S.S.	-	mean sums of squares
viz.	-	Namely
C.V.	-	Coefficient of variation
GM	-	Grand mean
C.D.	-	Critical difference
GA	-	Genetic advance
Min	-	Minimum
Max	-	Maximum
No.	-	Number
PCV	-	Phenotypic coefficient of variation
GCV	-	Genotypic coefficient of variation
RH	-	Relative heterosis
BP	-	Better parent heterosis
h^2 (bs)	-	Heritability in broad sense
SSR	-	Simple Sequence Repeats
G	-	Genotypes
P	-	Parents
F	-	Females
M	-	Males

H	-	Hybrids
σg	-	Genotypic variance
σp	-	Phenotypic variance
mt	-	Million tonnes
mha	-	Million hectare
DFH	-	Days to 50% heading
DM	-	Days to maturity
PH	-	Plant height
ER	-	Ear length
PL	-	Peduncle length
TGW	-	Thousand grain weight
BYPP	-	Biological yield per plant
HI	-	Harvest index
CT	-	Canopy temperature
CC	-	Chlorophyll content
RWC	-	Relative water content
GYPP	-	Grain yield per plant

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Date:

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(Rana Saha)

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is the world's second most important staple food crop for more than 35 percent of world's population next to the rice. It is cultivated under a wide range of climatic conditions favoured by cool, moist weather followed by dry warm weather. It produces about 20% food resources of the world.

India is the second largest wheat producer in the world next to China with a production level of 95.91million tonnes (FAO, 2015). Madhya Pradesh is the third largest producer state of wheat with area, production and productivity are 5.60 million hectare, 184.10 lakh tonnes and 3,115 kg per hectare, respectively with the ratio of cultivated *T. aestivum* and *T. durum* is 80:20 (Anonymous, 2015).

Despite remarkable growth in food production, the risks were exposed by food crisis in the recent years. Therefore, wheat production must continue to increase by 2% annually, more particularly in developing world including South-East Asia until 2020 to meet future demands imposed by population and prosperity growth (Reynolds and Tuberosa, 2008). Accordingly, understanding and improving plant survival and growth under restricted water availability is of central significance in contemporary plant science. This challenge will probably be further compounded by reduced water availability and increased temperature due to global warming.

The crop season of wheat ranges from 100 to 135 days for normally planted crop in India. The two most important phases of crop growth are pre-anthesis and post-anthesis. The pre-anthesis phase that determines the yield potential of the crop includes:

(i) Germination to seedling emergence (ii) Canopy development and conversion of the vegetative meristem to reproductive meristem and spike initiation (iii) Spikelet development – first spikelet initiation to the formation of the terminal spikelet and (iv) Ear emergence and anthesis. The period from anthesis to maturity is the grain formation process which is termed as post anthesis periods/grain filling period (GFP).

In India, breeding for specific situation in wheat is becoming important because of fast growing area under delayed planting due to rice - wheat crop rotation, where crop is exposed to high temperature stress at the post anthesis phase. Hence, now breeding for drought tolerance has become an integral component of wheat improvement at both National and International levels.

Since, the estimation of genetic parameters like variability, heritability, genetic advance, character association and path coefficient serve as an important tool in breeding programmes to improve the concern traits. To have better understanding of these parameters, estimation of association analysis and principal component analysis among some important traits for selection might be helpful for yield under drought condition. Simultaneous inheritance of characters that help to decide breeding strategies may vary with environmental conditions and set up of experimental genotypes. Hence, it is essential to conduct studies in different environment with diverse available genotypes.

The interaction effects of wheat genotypes with water and temperature stress on grains, days to maturity, plant height, peduncle length, number of grains per ear, number of spikelets per spike, 1000- grain weight, chlorophyll content, canopy temperature and RWC have generally been worked out which were established facts to contribute more for yield under restricted irrigation.

Looking to the above facts, the present investigation has been planned to study effects of drought stress on wheat crop during vegetative, reproductive and grain filling stages by planting wheat genotypes under restricted irrigated condition. Morphological and physiological response to drought and heat stress and defense mechanism will be emphasized and different methods for evaluation and breeding for drought tolerance will be elucidated with the following objective.

Objectives

1. To determine the genetic parameters of variability for yield and yield components
2. To assess the extent of correlation among characters under studies
3. To find out direct and indirect effects of various traits on grain yield
4. To identify suitable genotypes using principal component analysis

REVIEW OF LITERATURE

The present investigation was conducted to estimate the correlation coefficient, heritability, genetic advance, path coefficient and principal component analysis for high temperature tolerance and yield contributing characters in bread wheat (*Triticum aestivum* L.).

The relevant literature related to the present investigation “Genetic studies of Wheat Genotypes under Restricted Irrigated condition” has been furnished under the following heads:

2.1 Genetic parameters of variability

2.1.1 Coefficient of variation

2.1.2 Heritability and genetic advance

2.2 Correlation coefficient analysis

2.3 Path coefficient analysis

2.4 Principal component analysis

2.1 Genetic parameters of variability

The presence of genetic variability is a prerequisite in a breeding programme for the improvement of any crop plant. The phenotypic variability expressed by a genotype or a group of genotypes in any species can be partitioned into genotypic and phenotypic components. The genotypic component being the heritable part of the total variability, its magnitude on yield and its component characters influences the selection strategies to be adopted by the breeders. The efficiency of selection largely depends upon magnitude of genetic variability present in the plant population. Thus the success of genetic improvement in any character depends on the nature of variability present in the gene pool for that character. Related literature available for genetic variability on wheat is as follows:

2.1.1 Coefficient of variation

Genetic variability in a population is important for biodiversity, because without variability, it becomes difficult for a population to adapt environmental

changes. Hence, variability is the most key aspect of any research for a breeder, amount of which determining the extent of sources of selection. Various parameter of genetic variability are mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad sense heritability and genetic advance.

The idea of partitioning of variance was given by Fisher (1918), further many workers also suggested various technique for estimation of components of variation.

Pawar et al. (2002) studied the genetic variability for yield and yield components in 50 wheat cultivars and observed high genetic variability for number of days to 50% flowering, plant height, number of productive tillers per plant, length of spike, number of spikelets, grains per ear, 1000-grain weight and grain yield. They recorded highest genotypic and phenotypic coefficient of variation for plant height

Majumder et al. (2008) studied twenty diverse genotypes and observed highly significant genotypic and phenotypic variances in all the traits with little higher phenotypic variations as usual. Similarly, the low differences between the phenotypic and genotypic coefficients of variations indicated low environmental influences on the expression of these characters.

Eid (2009) revealed highly significant differences among genotypes and crosses under irrigated and drought sown for traits like plant height, spike length, number of spikes per plant, number of grains per spike, 50% heading date and 1000- grain weight.

Kahrizi et al. (2010) reported 18 experimental durum wheat and two checks under rainfed condition significant variation among genotypes for the traits plant height, no. of productive tillers, peduncle length, flag length, leaf dry weight, stem dry weight, spike dry weight, spike height, leaf area ratio and net assimilation rate.

Soleman Mohamed Al-Otayk (2010) combined analysis of variance showed that plant height, spike length, number of kernels per spike, harvest index and grain yield were significantly influenced by years, sowing dates, and genotypes. The results showed that sowing at the first date increased plant

height, grain yield, and harvest index. Highly significant genotype differences were recorded for all characters.

Zecevic et al. (2010) reported variability and components of variance for number of grains per spike and grain weight per spike in 10 winter wheat varieties from different selection centers. The average variation coefficient for number of grains per spike was 17.4%, and for grain weight per spike was 21.4%. The lowest variability for number of grains per spike and grain weight per spike was established in Sterna variety ($V=13.0\%$; 16.2% , respectively) and the highest in Norin 10 variety ($V=21.6\%$; 25.1% , respectively).

Ali and Shakor (2011) found high genetic variation for plant height, number of spikes, 1000 grain weight, biological yield and grain yield in durum wheat.

Nouri et al. (2011) reported highly significant genotypic differences for relative water content, plant height, biomass, number of grains per spike and grain yield in rainfed and irrigated conditions. This showed that drought stress reduced the yield of some genotypes while others were tolerant to drought, suggesting genetic variability of drought tolerance in this material.

Taheri et al. (2011) studied seven traits *viz.*, grain yield, 1000 grain weight, biomass, harvest index, plant height, main spike length and awn length in 17 spring wheat lines with variable responses to drought stress *i.e.* normal irrigation, after anthesis drought stress condition, and no irrigation. They found indicated that there were significant differences among the genotypes for all studied traits. For biomass, 1000- grain weight, grain yield and harvest index, there was no significant interaction between genotypes and levels of stress.

Aharizad et al. (2012) revealed significant differences among the lines for days to heading, peduncle length, spike length, plant height, number of spikelet per spike, number of spikes, number of grain per spike, 1000- grain weight, grain yield, percent of grain protein, and harvest index observed higher level of genetic variation for peduncle length, number of spikes and grain yield.

Al-Tabbal and Al-Fraihat (2012) observed significant differences among the genotypes for all the characters. The estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were high for grain yield per plant, plant height, biological yield, kernel weight and number of kernels per main spike.

Kalimullah et al. (2012) observed significant variability in forty one bread wheat genotypes for number of grains per spike, number of tillers per plant, 1000-grain weight and grain yield per plant. The estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were high for grain yield per plant and number of tillers per plant. The remaining traits exhibited moderate to low PCV and GCV.

Talebi and Fayyaz (2012) observed highest PCV value for number of seeds per spike under normal condition, while it was highest grain yield at drought and stress condition. The GCV values were the lowest (<2%) for harvest index and highest (12%) for plant height, number of seeds per spike and plant grain yield, 1000-seeds weight and plant biomass as well as number of seeds per m², also showed relatively low GCV values (3.8-8.8%).

Baloch et al. (2013) revealed significant differences among the genotypes for all the traits studied. The variety TD-1 produced maximum tillers per plant, more spikelets per spike and gave higher grain yield per plant, more seed index and harvest index. Sarsabz produced longer spike length, more spikelets and grains per spike, however, Sundar recorded taller plants.

Degewione and Alamerew (2013) reported high phenotypic and genotypic coefficient of variation for number of tillers per plant and grain yield per plot. High genetic coefficient of variation was recorded in grain yield per plot and days to heading.

Hamam (2013) revealed that traits *viz.*, plant height, days to heading, spikes per plant, 1000-kernel weight and grain yield were significantly affected by genotypes under heat stress treatments.

Nukasani et al. (2013) studied one hundred fourteen pre-breeding lines of wheat and reported high values of GCV and PCV for tillers per meter and grain yield per meter, whereas, moderate values for rest of the traits.

Shukla and Moitra (2013) found high phenotypic and genotypic coefficient of variation for number of tillers per plant, spike density and number of ears per plant. They observed high PCV% for grain yield per plant and high GCV% for number of grains per spike, grain yield per plant and harvest index.

Singh and Upadhyaya (2013) observed significant differences among the all characters except, number of effective tillers per plant and spike length. A broad range of variation was observed for grain yield per ha, plant height at maturity and number of grains per spike.

Bala et al. (2014) studied three wheat genotypes C 273 (heat tolerant) PBW 343 and PBW 550 (susceptible) under normal and heat stress (late sowing) conditions. Grain yield, no of grain per kernel, plant height, grain filling duration, peduncle length, peduncle weight and 1000 kernels weight were measured. High temperature significantly decreased all traits specially grain yield (26% and 54.2%), 1000-kernel weight (24% and 31%) and grain filling duration (3% and 9%) in tolerant and susceptible genotypes, respectively. Grain yield (54%) was most affected and grain filling duration (9%) was least affected by heat stress.

Kumar et al. (2014) observed that phenotypic coefficient of variation higher than genotypic coefficient of variation indicating lesser effect of environment on the expression of characters studied. Highest estimates of GCV and PCV were observed for grain yield per plant followed by biological yield and harvest index.

Dharmendra and Singh (2015) studied 20 genotypes under various environments and found high estimates of PCV and GCV for grain per spike, grain yield per plant, plant height followed by 1000-grain weight.

2.1.2 Heritability and genetic advance

Heritability in broad sense is the ratio of genotypic variance to total variance (phenotypic variance). It is calculated from total genetic variance which is consists of additive, dominance and epistatic variances. The estimates of broad sense heritability help the plant breeder in selection of elite genotypes from homozygous populations.

Genetic advance refers to the improvement in the genetic value of the selected single plant over the base population and is the measure of genetic gain under selection. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection than the heritability estimates alone.

Ghimiray and Sarkar (2000) found high heritability estimates along with grains per spike, 1000- grain weight, grain yield and plant height.

Dwivedi et al. (2002) reported high heritability and genetic advance for 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

Sharma and Garg (2002) indicated high heritability accompanied with high genetic advance in case of plant height, number of effective tillers per plant, number of spikelets per spike, ear length, number of grains per spike. 1000 grain weight and yield per plant indicated that most likely the heritability was due to additive gene effects and selection might be effective in early generations for these traits.

Kumar et al. (2003) reported high heritability coupled with high genetic advance for plant height, number of spikelets per ear, 1000-grain weight and days to 50% heading.

Kumar and Mishra (2004) observed high heritability coupled with high genetic advance as percentage of mean for number of tillers per plant, 1000- kernel weight, plant height and number of spikelets per plant.

Aycicek and Yildirim (2006) studied yield components for 20 bread wheat genotypes. They observed low heritability for the characters such as grain yield, spike number per square meter, plant height, grain number per spike, grain weight per spike, 1000 kernel weight and days to heading

Memon et al. (2007) observed high heritability and high genetic advance for plant height, number of spikelets per spike and number of grains per spike, in progeny Khirman x RWM-9313.

Majumder et al. (2008) obtained high heritability with high genetic advance with plant height, grains per spike, 100-grain weight, harvest index and grain yield.

Shankarrao et al. (2010) recorded high heritability coupled with high genetic advance for grain weight per spike, per plant and per meter square, number of grains per spike, 1000-grain weight and the grain protein content indicating the characters to be under additive genetic control and also scope of improvement through direct selection.

Monpara (2011) reported high heritability along with high genetic advance for number of grains per plant.

Yadav et al. (2011) studied sixteen wheat genotypes representing thirteen diverse wheat lines were crossed with well adapted varieties as testers in a Line x Tester design. The study revealed that days to maturity had the highest heritability followed by biological yield per plant, days to heading, 1000-grain weight, no. of tillers per plant, harvest index, grain yield per plant. spike length and plant height while total number of grains per ear had the lowest heritability. Biological yield per plant, tillers per plant and grain yield per plant had high heritability coupled with high genetic advance thereby indicating that selection for these characters would be effective.

Baranwal et al. (2012) observed high heritability with low genetic advance in per cent of mean for days to heading which indicated the involvement of non-additive gene action for the expression of this traits and selection for such trait might not be rewarding. High heritability with high genetic advance in per cent of mean for peduncle length, chlorophyll content, and grains per spike indicated that these traits were under additive gene control. Whereas, reported moderate heritability for spike length.

Baloch et al. (2013) reported high heritability for plant height, tillers per plant, spike length, spikelets per spike, grains per spike, grain yield per plant and harvest index.

Bhushan et al. (2013) recorded high heritability with high genetic advance for plant height, harvest index, biological yield and grain yield that indicated predominance of additive gene action in the inheritance of these

traits. They also reported that higher magnitudes of GCV and PCV for grain yield, biological yield, productive tillers per plant and plant height.

Farshadfar et al. (2013) reported high heritability coupled with high genetic advance for grain yield and chlorophyll content, whereas low heritability with moderate genetic advance for relative water content.

Fellahi et al. (2013) studied twenty nine bread wheat genotypes involving twenty hybrids and nine parents. Highest values of heritability were observed for plant height, days to 50% heading, thousand kernel weight, number of grains per spike and spike length. The highest genetic gain observed for number of grains per spike followed by chlorophyll content, plant height, number of spikes per plant and thousand kernel weight.

Mishra and Shukla (2013) reported high heritability coupled with high genetic advance for characters viz., dry gluten content, tillers per plant, protein content, sedimentation value, wet gluten content, biological yield per plant and grains per spike. While, high heritability coupled with low genetic advance was reported for days to 50% heading and days to maturity.

Nukasani et al. (2013) reported high heritability with high genetic advance for plant height, number of tillers, grain yield, grain weight per spike and spike length in wheat.

Kumar et al. (2014) observed high heritability with high genetic advance for number of tillers per plant, number of grains per spike, 1000-grain weight and ear length indicating the importance of these traits in selection for crop improvement.

Farshadfar and Estehghari (2014) observed high heritability estimates (>0.5) for all the characters investigated like yield (Ys), biomass (BI), harvest index (HI), thousand seed weight (TSW), number of seed per spike (NSPS), awn length (AL), plant height (PH), spike weight (SW) and peduncle length (FL) except spike length (SL). High heritability estimates associated with high genetic gain for Ys, TSW and AL reflecting involvement of additive gene action. Characters like HI, BI, NSPS, SW and PL showed high heritability coupled with moderate genetic advance indicating the chance of effective selection of these traits for improvement of grain yield. SL and PH displayed

low and high heritability with low genetic advance. Non-additive (dominance/epistasis) gene effects were more important for these traits.

Salman et al. (2014) studied sixty five wheat accessions for heritability and reported highest heritability and expected genetic advance for all the traits except chlorophyll concentration index, spike length and number of spikelet spike-1 which exhibited moderate heritability.

Dharmendra and Singh (2015) studied on 20 wheat genotypes showed high heritability for grain per spike, grain yield per plant, plant height, medium for 1000-grain weight and low for days to 50 % heading and days to maturity.

Fikre et al. (2015) observed High heritability values for days to heading, days to maturity, grain filling period, 1000 kernel weight, number of spikelet per spike, spike length and plant height. Among the characters 1000 kernel weight showed high values of genetic gain whereas days to maturity, grain yield, harvest index, productive tillers and number of grains per plant had moderate values of genetic advance as percent of mean.

2.2 Correlation coefficient

Correlation coefficient is a statistical measure which is used to find out the degree and direction of relationship between two or more variables. A positive value of correlation shows that the changes of two variables are in the same direction whereas in the negative correlation movements of two variables are in the opposite direction. There are three types of correlation viz., phenotypic, genotypic and environmental. Phenotypic correlation is the observable correlation between two variables. It includes both genotypic and environmental effects. Genotypic correlation on the other hand measures the inherent association between two variables. Searle (1961) describe the mathematical application of correlation at phenotypic, genotypic and environmental level. The literatures are available on correlation analysis in wheat are presented below:

Kashif and Khaliq (2004) reported that grain yield was highly significantly associated with plant height, spike length, spikelets per spike, grains per spike and 1000 -grain weight whereas, fertile tillers per plant was negatively and non -significantly correlated with grain yield.

Ali et al. (2008) observed that grain yield per plant showed highly significant positive correlation with number of productive tillers per plant, number of spikelets per spike and number of grains per spike and significant positive correlation with spike length.

Majumder et al. (2008) found that genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients in most of the studied traits. Spikes per plant, grains per spike, spike length, 1000 - grain weight and harvest index were the most important characters which possessed positive association with grain yield.

Kahrizi et al. (2010) found high correlations among the plant height, leaf dry weight, stem dry weight, spike dry weight, leaf area ratio and net assimilation ratio.

Khokhar et al. (2010) revealed that grain yield per plant had positive and highly significant correlated with days to maturity but negative and highly significant association with plant height.

Ali and Shakor (2011) found significant positive correlation of grain yield with 1000 grain weight, biological yield and harvest index in durum wheat.

Mohibullah et al. (2011) studied on 100 diverse wheat genotype and found that spike length showed positive significant correlation with number of spikelets per spike and grain yield per plant. While, positive correlation was observed for spike length and 1000- grain weight,. Number of spikelets per spike had highly significant correlation with grain yield per plant.

Chhibber and Jain (2014) studied on currently cultivated three bread wheat genotypes in Haryana, namely, HD 2932, HD 2967 and HD 2851 showed that the grain yield depicted significant positive correlation with shoot height, tiller number, vegetative dry matter content, and reproductive dry matter content and biological yield.

Dharmendra and Singh (2015) studied 20 wheat genotypes and observed that days to maturity, plant height, spike length, spikelets per spike, tillers per plant, grains per spike and 1000-grain weight were positively correlated with grain yield.

Khan and Kabir (2015) studied 25 genotypes and reported that grain yield had significant positive associations with all the traits studied *viz.*, plant height, tillers per m², spike length, grains per spike, 1000-grains weight, biological yield, grain yield and harvest index except 1000-grain weight.

Singh et al. (2015) evaluated 30 advance lines of bread wheat and their parents. At genotypic level, days to 50 per cent flowering exhibited significant positive correlation with days to maturity and negative correlation with plant height, 1000-grain weight, sedimentation value and protein content. Plant height exhibited positive correlation with hectoliter weight and tiller per plant showed positive correlation with yield per plant. 1000-grain weight was found to be positively correlated with sedimentation value and protein content. Gluten content exhibited positive correlation with sedimentation value and protein content. Sedimentation value exhibited positive correlation with protein content and negative correlation with yield per plant.

2.3 Path coefficient analysis

The path coefficient analysis is simply a standardized partial regression coefficient which splits the correlation coefficient into direct and indirect effects. Path analysis measures the cause of association of two variables. It is based on all possible simple correlation among various characters. It helps in determining yield contributing characters and useful in indirect selection. The concept of path coefficient was developed by Wright (1921). Path coefficient analysis was applied for assessment by Dewey and Lu (1959) in wheat grass, followed by Ramanujan and Rai (1963) in Brassica. The literatures available on path analysis in Wheat are presented below:

Khokhar et al. (2010) observed that the highest positive direct effect on yield was exhibited by days to maturity followed by days to heading.

Hannachi et al. (2013) found that above ground biomass and harvest index exerted positive direct effect on grain yield, whereas straw yield had a negative direct effect on grain yield. The highest indirect effects on grain yield were observed with straw yield, spikes number per plant, plant height and thousand-kernel weight through above ground biomass and with harvest

index via straw yield. However, plant height, spikes number per plant, number of kernels per spike and thousand-kernel weight exerted insignificant effects on grain yield.

Khan et al. (2013) studied on path coefficient and revealed that days to maturity, number of spikes per m² and 1000-grain weight had significant positive direct effects on grain yield. Number of grains/spike had also direct positive effect, but lower in magnitude. The indirect effect of heading days and plant height on grain yield was found mainly through maturity days and 1000-grain weight.

Nukasani et al. (2013) found maximum positive direct effects on grain yield with number of tillers per meter, grain weight per spike, number of grains per spike.

Singh and Upadhyay (2013) observed that grain yield per hectare had highest positive direct effect on grain yield per plant followed by 1000 grain weight. It was suggested that these characters could be considered as selection criteria in improving the grain yield.

Ata et al. (2014) revealed path analysis in both environments and found that plant height, 1000-grain weight and relative water contents contributed for the grain yield in positive way and plant height had negative direct effect on yield.

Kumar et al. (2014) observed that days to heading, harvest index and biological yield exhibited the highest positive direct effect on grain yield.

Fikre et al. (2015) studied sixty four bread wheat genotypes and observed that hectoliter weight, spike length, number of grains per plant and number of spikelets per spike had positive direct effects and positive correlation coefficients, except for number of spikelets per spike and number of grains per plant which had non-significant negative correlation with grain yield.

Singh et al. (2015) evaluated thirty advance lines of bread wheat along with their parents and observed that days to 50 per cent flowering had negative effect on grain yield. It contributed to grain yield indirectly via, 1000-

grain weight and flag leaf length whereas, number of tillers per plant and days to maturity exhibited positive direct effect on yield.

2.4 Principal component analysis

The principal component analysis is a multivariate statistical technique for exploration and simplifying complex data sets. The ability of this procedure to transform a number of possibly correlated variables into a smaller number of variables called principal components (Everitt and Dunn 1992). Each principal component is a linear combination of the original variables.

Leilah and Al-khateeb (2005) studied seven statistical procedures including; principal components analysis to determine the relationship between wheat grain yield and its components under drought condition of Saudi Arabia. The principal components analysis had grouped the estimated wheat variables into three main components which all together accounted for 74.4% of the total variation of grain yield and results showed that PC1 correlated moderately well with plant height, 1000-grain weight and weight of grain/spike. Meanwhile, the PC2 correlated moderately with spike diameter and number of grains per spike.

Sourour et al. (2010) evaluated 30 Tunisian durum wheat landraces for various yield contributing characters. In order to classify the accessions, the PCA was used. The PCA explained 59.61% of total variation in Tunisian germplasm. The first axis explained 37.53% of total variability and the most associated traits were thousand kernel weights, number of kernel per spike, plant height and flag leaf area. The second PCA axis explained 22.08% and was mostly related to days to heading, days to maturity and filling period.

Hailegiorgis et al. (2011) carried out an investigation with 49 bread wheat genotypes to assess the genetic diversity for yield and yield related traits. The genotypes were evaluated for 17 yield and yield related traits and showed wide variability for them and the result of principal component analysis revealed that nine principal components (PC1 to PC9) accounted nearly 80% of the total variation.

Koumber (2011) performed genetic analysis on 18 wheat parents to estimate the supremacy of additive, dominance and epistasis genetic variances following triple test cross analysis and the result of principal component analysis revealed that the first three principal components were significant and accounted for about 78.2% of the total variance of all characters.

Sajjid et al. (2011) studied 500 genotypes for two consecutive years to find out the diversity pattern among them and selected diverse parents for future breeding programs. Twelve quantitative traits were evaluated and result revealed that the number of kernels per plant, number of spike per plant, spike dry weight contributed towards significant principal components and were highly related to grain yield.

Tsegaye et al. (2012) conducted an experiment to examine the magnitude of genetic diversity among 23 durum wheat genotypes grown at adet, northwest Ethiopia and results showed that the first four principal components whose Eigen values were greater than one, accounted for 80.46% of the total variation of the original variables.

Khan and Kabir (2015) studied 25 spring wheat genotypes and evaluated for terminal heat stress tolerance in field environments using randomized block design with three replication under stress and non-stress condition. PCA revealed that the first PCA explained 0.64 of the variation with mean productivity, geometric mean productivity, yield index and stress tolerance and the second PCA explained 0.35 of the total variability co-related positively with the tolerance and yield stability index.

Rajpuri et al. (2015) studied terminal heat stress during anthesis and grain filling stages. 10 diverse lines were planted under normal and late sown conditions at two locations on Nepal and found that the first two factors two PCA analysis explained more than 97% variation. The first factor explained 62% variation for grain yield whereas, second factor contributed 35%.

MATERIAL AND METHODS

The present investigation entitled “Genetic Studies of Wheat Genotypes under Restricted Irrigated condition” was carried out during the *Rabi* season of 2015-16. The techniques followed and materials used during the course of investigation are presented under following subheads.

3.1 Experimental site

The experiment was carried out under Wheat Improvement Project Department of Plant Breeding and Genetics at Seed Breeding Farm, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P) under restricted irrigated conditions. The experimental area occupied was quite uniform in respect of topography and fertility.

3.2 Climate and weather

Jabalpur is situated at 23.90° N latitude and 79.58° E longitudes at an altitude of 411.87 M above the mean sea level. This region has subtropical, semi-arid climate. The main features are hot and dry summer and cold winter with occasional showers. The average rainfall is about 1300 -1400 mm, which is received mostly during July to September. Temperature varies from 4.9°C being minimum in December to 42.2°C being maximum in April. The 29.6 mm precipitations received at grain filling stage in the last week of February and first fortnight of March helped wheat crops thus saving one irrigation. The crop was grown under normal crop season. The meteorological data of crop season is presented in Table 3.1.

3.3 Experimental material

Source: Experimental material consists of 30 wheat genotypes including 3 checks *viz.*, DBW71, DBW107 and K307 obtained from Wheat Improvement Project, Department of Plant breeding and Genetics, JNKVV, Jabalpur during *Rabi* season, 2015-16. The experiment was conducted in three replications under Randomized Complete Block Design. Each plot consisted of six rows of 2.5 m length and 22.5 cm. Details of genotypes are given in Table 3.2.

Table 3.2 The details of wheat genotype

S. No.	Name of genotype	Name of pedigree
1	PYT-2	XING82.2661/2*KAUZ//20SAWSN70
2	PYT-6	XING82.2661/2*KAUZ//20SAWSN70
3	PYT-16	DBW71
4	PYT-21	SGH19/SGH13
5	PYT-22	SGH19/SGH13
6	PYT-23	SGH19/SGH13
7	PYT-24	SGH19/SGH13
8	PYT-25	SGH19/SGH13
9	PYT-27	35IBWSN159*2/DBW17/3/Alter84/Ae squarrosa (229)//Seri
10	PYT-40	SGH10/10HRWYT36
11	PYT-46	35 IBWSN162/35IBWSN249
12	PYT-47	35IBWSN159/4/CHEN/Ae. squarrosa (TAUS)//BCN/3/KAUZ
13	PYT-49	XING82.2661/2*KAUZ//35IBWSN539
14	PYT-51	DBW107
15	PYT-57	CHEN/Ae.sq(TAUS)//BCN/3/KAUZ/4/DBW17
16	PYT-58	Munia/CHTO/3/PFAU/BOW//VEE79/4/CHEN/Ae.sq(TAUS)//BCN/5/DBW16
17	PYT-60	35IBWSN159/3/Altar.84/Ae.sq(229)//Seri
18	PYT-61	35IBWSN159/3/Altar.84/Ae.sq(229)//Seri
19	PYT-66	35IBWSN159/DBW17
20	PYT-68	35IBWSN159/DBW17
21	PYT-69	35IBWSN159/DBW17
22	PYT-89	35IBWSN 244/DBW17
23	PYT-97	15KBSN98/UP2425
24	PYT-101	K307
25	PYT-104	4EGPSN109/4EGPSN83
26	PYT-109	21SAWYT339
27	PYT-115	31SAWSN3054
28	PYT-118	31SAWSN3063
29	PYT-120	31SAWSN3091
30	PYT-122	31SAWSN3106

3.4. Observations recorded

The observations were recorded on five randomly plants taken from each plot and from each replication for the following characters and per plant data were obtained by averaging the values.

3.4.1 Morphological and yield traits

3.4.1.1 Days to 50% heading (days)

The number of days required from sowing to ear head emergence for 50% flowering was recorded.

3.4.1.2 Days to maturity (days)

The number of days required to achieve physiological maturity was recorded.

3.4.1.3 Plant height (cm)

Plant height of sampled plants was measured in centimeters from ground level to tip of the tallest spike (excluding awns) at the time of maturity.

3.4.1.4 Number of effective tillers per plant

It was recorded by counting the number of productive tillers of the plant excluding non-productive tillers.

3.4.1.5 Number of spikelets per spike

Number of spikelets were counted in each spike of the sampled plants and averaged to find average number of spikelets per spike.

3.4.1.6 Ear length (cm)

The length of the spike was recorded in cm from base to tip of spike excluding awns.

3.4.1.7 Ear weight (g)

The weight of the ear was recorded in gm.

3.4.1.8 Peduncle length (cm)

The length of the peduncle was recorded in cm.

3.4.1.9 Number of ears per plant

Number of ears was counted in each plant of the sampled plants and to find average number of ears per plant.

3.4.1.10 Number of grains per ear

Total number of grains in the main spike of sampled plants was counted after harvesting.

3.4.1.11 1000-grain weight (g)

The weight of 1000 randomly selected grains from the seed mixture of plants of each replication was recorded.

3.4.1.12 Biological yield/plant (g)

Each of the selected plants was harvested at maturity and weight recorded in grams after complete sun drying excluding roots.

3.4.1.13 Harvest index (%)

The harvest index was calculated by using the following formula and expressed in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield / plant (g)}}{\text{Biological yield / plant (g)}} \times 100$$

3.4.1.14 Grain yield/plant (g):

The grains obtained from each plant were weighed in grams and average over 10 plants per replication.

3.4.2 Physiological traits

3.4.2.1 Leaf canopy temperature (°C)

Leaf canopy temperature was measured using Infrared thermometer at the grain filling stage in the day time of minimum humidity, high temperature, full sunshine and least wind velocity i.e. at 2 to 4 PM.

3.4.2.2 Chlorophyll content index (SPAD)

Chlorophyll content of leaf was measured by chlorophyll content meter (CCM200) at tillering stage and after 50% flowering. The chlorophyll content of leaf obtains from average.

3.4.2.3 Relative water content (%)

RWC was measured from flag leaves at anthesis. Immediately after cutting at the base of lamina, leaves were sealed within plastic bags and transferred to the laboratory. Fresh weight (FW) was measured after excision and the full turgid weight (TW) after the dehydration of the leaves by placing them in a test tube containing 100 ml distilled water for 24 hrs at room temperature (about 21⁰C). After soaking, leaves were carefully blotted dried with tissue paper. Dry weight (DW) was measured after oven drying at 70 ⁰ C for 72 hrs. The RWC was calculated from the equation as follows:

$$RW\ C\ (\%) = \frac{(FW - DW)}{(TW - DW)} \times 100$$

Where

FW = Fresh weight

TW = Turgid weight

DW = Dry weight

RWC = Relative water content

3.5. Statistical analysis

The statistical analysis of data on individual characters was carried out on the mean values over three replications. The statistical methods adopted were as follows:

Mean: The mean was calculated by following method:

$$\text{Grand mean } (\bar{X}) = \frac{\sum x_i}{N}$$

Where,

$\bar{X}$ = Grand mean or over all mean of the observation

$\sum x_i$ = Sum of all observations; [i= 1, 2, 3 n]

N = Number of observations

Range

Range is the difference between the least and the greatest terms of a series of observation and thus provides the information about the variability present in the genotypes.

Coefficient of variation (CV %)

Genotypic and phenotypic coefficient of variation was computed, using formula given by Burton (1952).

$$\text{Genotypic coefficient of variation (GCV \%)} = \frac{\sqrt{\sigma^2_g}}{\bar{X}} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV \%)} = \frac{\sqrt{\sigma^2_p}}{\bar{X}} \times 100$$

Where,

$$\sqrt{\sigma^2_g} = \text{Genotypic standard deviation}$$

$$\sqrt{\sigma^2_p} = \text{Phenotypic standard deviation}$$

$$\bar{X} = \text{General mean of particular character}$$

The estimates of PCV and GCV were classified as low, moderate and high according to Sivasubramanian and Madavamenon (1973).

$$> 20 \% = \text{High}$$

$$10-20 \% = \text{Moderate}$$

$$<10 \% = \text{Low}$$

3.5.1 Analysis of variance (ANOVA)

The analysis of variance (ANOVA) for all characters was carried out separately.

Table 3.3 The skeleton of Analysis of variance

S.N.	S.V.	d.f.	S.S.	M.S.S.	F(cal)
1	Replication	(r-1)= 2	SSr	RMS	RSS/ ESS
2	Treatment	(t-1)=29	SS _t	TSS	TSS/ ESS
3	Error	(r-1)×(t -1) =58	SS _e	EMS	
	Total	(rt -1)=89			

Where,

r = no. of replications

t = no. of genotypes

RMS = Replication mean square

EMS = Error mean sum of square

TSS = Treatment sum of square

A significant value of F -test indicates that the test entries differ significantly among themselves, which requires computing the critical difference (CD).

$$\text{Coefficient of variation (CV \%)} = \frac{\sqrt{\text{EMS}}}{\text{GM}} \times 100$$

$$\text{Standard error of difference (SE}_d\text{)} = \sqrt{\frac{\text{EMS}}{r}}$$

$$\text{Critical Difference (CD)} = t_{(0.01)} \times \text{SE}_d$$

Where,

G.M. = General mean

$t_{(0.01)}$ = t- value at 1% probability level

r = number of replication

3.5.2 Parameters of Genetic variability

In order to assess and quantify the genetic variability among the genotypes for the characters under studies, the following parameters were estimated.

3.5.2.1 Estimation of variance components

Phenotypic and genotypic coefficient of variation was computed, using formula given by Burton (1952).

$$\text{Genotypic coefficient of variation (GCV \%)} = \frac{\sqrt{\sigma^2 g}}{\bar{X}} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV \%)} = \frac{\sqrt{\sigma^2 p}}{\bar{X}} \times 100$$

Where,

$$\sqrt{\sigma^2 g} = \text{Genotypic standard deviation}$$

$$\sqrt{\sigma^2 p} = \text{Phenotypic standard deviation}$$

$$\bar{X} = \text{General mean of particular character}$$

3.5.2.2 Heritability (h^2 bs)

Heritability in broad sense was calculated by the method proposed by Hanson et al. (1956).

$$h^2 (\text{bs \%}) = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where

$$h^2 (\text{bs}) = \text{heritability in broad sense}$$

$$\sigma^2 g = \text{Genotypic variance}$$

$$\sigma^2 p = \text{Phenotypic variance}$$

3.5.2.3 Genetic advance

The estimation of genotypic and phenotypic variances and heritability were used to determine the expected genetic advance as suggested by Johnson et al. (1955) and expressed as -

$$GA = K \times \sigma_p \times h^2$$

Where,

K = Selection intensity (2.06 at 5% level)

σ_p = Phenotypic standard deviation

h^2 = Heritability (bs) in fraction

3.5.2.4 Genetic advance as percentage of mean

This was expressed by following formula

$$GA \text{ as a \% of mean} = \frac{GA}{\bar{X}} \times 100$$

Where,

GA = Genetic advance

$\bar{X}$ = Mean

3.5.2.5 Association analysis

3.5.2.5.1. Correlation coefficient

Correlation coefficients were calculated for combination of all characters under study at genotypic, phenotypic and environmental levels with the help of formula suggested by Miller et al. (1958).

$$r_{ij} = \frac{Cov(ij)}{\sqrt{(\sigma^2 i)(\sigma^2 j)}}$$

Where

r_{ij} = Correlation coefficient between i^{th} and j^{th} traits

$Cov(ij)$ = Covariance between i^{th} and j^{th} traits

$\sigma^2 i$ = Variance of i^{th} trait

$\sigma^2 j$ = Variance of j^{th} trait

To test the significance of phenotypic correlation coefficients, the estimated values were compared with the tabulated values of Fisher and Yates (1963) at $n-2$ d.f. at two levels of probability, viz., 5% and 1%.

$$T_{\text{cal.}} = \frac{r}{\sqrt{(1-r^2)}} \times \sqrt{n-2} \quad \text{at } (n-2) \text{ d.f.}$$

3.5.2.5.2. Path coefficient analysis:

The proportion of direct and indirect contributions of various characteristics to the total correlation coefficients with seed yield was estimated through path coefficient analysis as suggested by Wright (1921, 1934) and elaborated by Dewey and Lu (1959).

Path coefficient is a standardized partial regression, which measures the direct influence of one variable upon another and allows partition of correlation coefficient into components of direct and indirect effects.

To estimate various direct and indirect effects, the following set of simultaneous equations were formed and solved for estimating direct and indirect effects.

$$r_{1y} = P_{1y} + r_{12}P_{2y} + r_{13}P_{3y} + \dots + r_{1l}P_{ly}$$

$$r_{2y} = r_{2y}P_{1y} + P_{2y} + r_{23}P_{3y} + \dots + r_{2l}P_{ly}$$

$$r_{ly} = r_{l1}P_{1y} + r_{l2}P_{2y} + r_{l3}P_{3y} + \dots + P_{ly}$$

Where,

r_{1y} to r_{ly} = Coefficient of correlation between causal factor 1 to l and dependent character y

r_{12} to $r_{l-1,l}$ = Coefficient of correlation among causal factors themselves

P_{1y} to P_{ly} = Direct effects of characters 1 to l on character y .

Residual effect, which measures the contribution of the characters not considered in the causal scheme, was obtained as

Residual effect

$$(P_{RY}) = \sqrt{1 - R^2}$$

Where,

$$R^2 = \sum_{iy} P_i^2 Y + 2 \sum_{\substack{i \neq j \\ i > j}} P_{iy} P_{jy} R_{ij}$$

3.5.3 Principal Component Analysis

It is a multivariate statistical analysis to reduce the data with large number of correlated variables into a substantially smaller set of new variables through linear combination of the variables that accounts most of the variation present in the original variables. Principal components are generally estimated either from correlation matrix or covariance matrix. When the variables are measured in different units, scale effects can influence the composition of derived components. In such situations it becomes desirable to standardize the variables. In the present investigation correlation matrix was used to extract the principal components.

PCA is a well-known method of dimension reduction (Massy, 1965; Jolliffe, 1986) which seeks linear combinations of the columns of X with maximal variance, or equivalently, high information. It is routinely applied in chemometrics with the goal of providing the most compact representation of the data. The original p variables $X = [x_1 \dots x_p]$ are transformed in a new predictor set $T = [t_1 \dots t_k]$, with $k \leq \min(n - 1, p)$. The new variables t_j , called scores, are a weighted average of the original X variables. The principal components are the eigenvectors, u_j from the Eigen decomposition of $X'X$ (and of the sample covariance matrix S , up to a constant). PCA sequentially maximizes the variance of a linear combination of the original predictor variables.

$$U_j = \arg \max \text{Var}(Xu),$$

$$u=1$$

Subject to the constraint that $u' u = 1$ for all $1 \leq i < j$. This ensures that $t_j = Xu_j$ is uncorrelated with all the previous linear combinations $t_i = Xu_i$. The principal components are ordered in terms of the amount of variation of the original data they account for. The first principal component direction has the property that $t_1 = Xu_1$ has the largest sample variance among all normalized linear combinations of the columns of X . Each subsequent component gives combinations with the largest possible variance which is uncorrelated with those that have been taken earlier.

There are various standard approaches to find the principal components, e.g. taking the singular value decomposition of X . In chemometrics, it is common to estimate the principal components using the nonlinear iterative partial least-squares (NIPALS) algorithm (Wold, 1966). This is because the number of required components is usually much less than the total possible number ($k - p$). In fact, the NIPALS algorithm does not calculate all the principal components at once, but it first calculates t_1 and u_1 from the X matrix. Then the outer product $t_1 u_1'$ is subtracted from X and the residual X_2 is calculated. In turn, this residual can be used to calculate t_2 and u_2 .

RESULTS

The experimental findings of the present study have been reported here in under the following heads:

4.1 Parameters of genetic variability

4.1.1 Analysis of variance

4.1.2 Mean and range

4.1.3 Genotypic and phenotypic coefficient of variation

4.1.4 Heritability

4.1.5 Genetic advance

4.2 Association analysis

4.2.1 Correlation coefficient analysis

4.2.2 Path coefficient analysis

4.3 Principal component analysis

4.1 Parameters of genetic variability

4.1.1 Analysis of variance

The mean sum of square based on analysis of variance of 30 genotypes of wheat for 17 characters *viz.*; days to 50% flowering, days to maturity, plant height, number of effective tillers, number of ears per plant, number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, 1000-grain weight, yield per plant, biological yield per plant, harvest index, relative water content, chlorophyll content and canopy temperature have been presented in Table 4.1. It was observed that estimated variance due to varieties for all phenological, physiological, morphological and yield contributing traits were highly significant.

The parameters of genetic variability *viz.*, mean, range, phenotypic and genotypic coefficient of variation (%), heritability in broad sense (%) and genetic advance as percentage of mean for each trait are presented in Table 4.2.

Table 4.1 Analysis of variance (ANOVA) for phenological and yield contributing traits

S. No.	Source of variation	df	Mean Sums of Squares								
			DFF	DM	PH	PL	EL	EW	NETP	NEPP	NSPE
1.	Replication	2	58.97	90.13	28.28	8.40	9.01	4.08	3.55	3.07	2.49
2.	Treatment	29	32.53**	31.35**	59.15**	20.11**	4.60**	1.67**	3.63**	3.70**	5.78**
3.	Error	58	0.63	0.66	0.35	0.04	0.05	0.02	0.01	0.02	0.016
4.	S.E	-	0.45	0.46	0.34	0.12	0.13	0.08	0.07	0.09	0.07
5.	C.D 5%	-	1.30	1.32	0.97	0.34	0.38	0.24	0.21	0.26	0.20
6.	C.D 1%	-	1.73	1.76	1.30	0.46	0.50	0.32	0.28	0.35	0.27

S. No.	Source of variation	Df	Mean Sums of Squares							
			NGPE	TGW	BYPP	HI	GYPP	CC	CT	RWC
1.	Replication	2	2.14	2.14	0.09	12.07	1.19	0.62	0.56	2.18
2.	Treatment	29	116.46**	29.50**	167.29**	112.16**	8.05**	24.35**	7.25**	50.16**
3.	Error	58	0.02	0.09	0.09	0.24	0.02	0.09	0.06	0.02
4.	SE	-	0.09	0.17	0.17	0.28	0.08	0.17	0.14	0.08
5.	CD 5%	-	0.26	0.49	0.49	0.81	0.25	0.50	0.41	0.25
6.	CD 1%	-	0.34	0.65	0.65	1.07	0.33	0.67	0.55	0.33

** Significant at 1% *Significant at 5%

DFF-Days to 50% flowering, DM-Days to maturity, PH-Plant height, PL-Peduncle length, EL- Ear length, EW- Ear weight, NETP-Number of effective tillers per plant, NEPP-Number of ears per plant, NSPS-Number of spikelets per spike, NGPE- Number of grains per ear, TGW-Thousand grain weight, BYPP-Biological yield per plant, HI-Harvest index, GYPP-Grain yield per plant, CC-Chlorophyll content, CT-Canopy temperature, RWC-Relative water content.

4.1.2 Mean and Range

The mean and range of genotypes for all the 17 characters studied in the present investigation has been discussed as under

Days to 50% flowering

Days to 50% flower initiation of different genotypes ranged from 69.66 to 82.66 days with a mean value of 76 .65 days. The earliest flowering was found in PYT-2 (72.66) followed by PYT-40 (71.66), PYT-109 (71.00) and PYT-122 (69.66). The latest being in the PYT- 27 (80.66).

Days to maturity

Days to maturity varied as of 116.33 to 127 .66 days, with a mean value of 122.23 days. The earliest maturity was found in PYT-122 (116.33) followed by PYT-2 (109), PYT-21 (117.33). The genotypes PTY-49 (126.66) was latest in maturity.

Plant height

Plant height ranged from 87.43 to 108.60 cm, with a mean value of 97.7 cm. The highest height found in PYT-49 (108.60) followed by PYT-122 (105.53), PYT-40 (103.66). The genotypes PYT-69 (87.43) was found lowest in height.

Peduncle length

Peduncle length ranged from 11.86 to 21.0 cm, with a mean value of 16.42 cm. The highest length found in PYT-122 (21.0), followed by PYT-49 (20.90), PYT-22 (20.40). The genotypes PTY-57 (11.86) was found lowest in length.

Ear length

Ear length ranged from 9.0 to 13.1 cm, with a mean value of 10.93 cm. The highest length found in PYT-49 (13.10), followed by PYT-40 (12.83), PYT-22 (12.36) and the lowest length found in PYT-69 (9.0).

Ear weight

Ear weight ranged from 1.8 to 4.2 gm, with a mean value of 2.94 gm. The genotype PYT-49 (4.26) was maximum in weight followed by PYT-40 (4.1), PYT-22 (4.0) and minimum weight found in PYT-69 (1.80).

Number of effective tillers per plant

Number of effective tillers per plant ranged from 4.46 to 8.7 with a mean value of 6.29. The maximum tillers found in PYT-101 (8.7), followed by PYT-61 (7.8), PYT-115 (7.76) and minimum tillers found in PYT-27 (4.63), PYT-120 (4.53) and PYT-4 (4.46).

Number of ears per plant

Number of ears per plant ranged from 4.36 to 8.67 with a mean value of 6.21. The maximum ears found in PYT-101 (8.67), followed by PYT-61 (7.76), PYT-115 (7.73) and minimum ears found in PYT-25 (4.36).

Number of spikelets per spike

Number of spikelets per ear ranged from 12.73 to 17.50 with a mean value of 14.94. The maximum spikelets are found in PYT-40 (17.50), followed by PYT-60 (17.50), PYT-104 (17.23) and minimum spikelets are found in PYT-58 (13.26), PYT-21 (13.23) and PYT-57 (12.73).

Number of grains per ear

Number of grain per ear ranged from 32.63 to 52.93 with a mean value of 44.74. The maximum numbers of grain are found in PYT-40 (52.93), followed by PYT-104 (52.86), PYT-69 (52.70) and minimum number of grains are found in PTY-23 (32.63)

1000 grain weight

1000 grain weight ranged from 35.33 to 46.06 gm with a mean value of 40.61gm. The maximum weight found in PYT-69 (46.06) followed by PYT-60 (45.80), PYT-57 (45.66) and minimum weight found in PYT-47 (35.46), PYT-2 (35.36) and PYT-25 (35.33).

Biological yield per plant

Biological yield per plant ranged from 20.36 to 46.8 gm with a mean value of 35.11 gm. The highest yield found in PYT-49 (46.80), followed by PYT-57 (45.0), PYT-104 (44.26) and lowest yield found in PYT-27 (20.43) and PYT-24 (20.36).

Harvest index

Harvest index ranged from 19.9 to 46.23 with a mean value of 27.16. The genotype PYT-27 (46.23) was highest harvest index followed by PYT-60 (38.73), PYT-22 (36.56) and lowest harvest index was found PYT-47 (19.9).

Grain yield per plant

Grain yield per plant ranged from 5.83 to 11.6 gm, with a mean value of 9.27 gm. The maximum yield was found in PYT-57 (11.6), PYT-60 (11.56), PYT-104 (11.23) and minimum yield was found in PYT-25 (6.56), PYT-2 (6.23) and PYT-24 (5.83).

Chlorophyll content

Chlorophyll content ranged from 37.6 to 46.36, with a mean value of 42.07. The highest chlorophyll content was found in PYT-47 (46.36), PYT-118 (46.30), PYT-27 (45.76) and lowest chlorophyll content was found in PYT-58 (38.60), PYT-109 (38.50) and PYT-46 (37.60).

Canopy temperature

Canopy temperature ranged from 17.73 to 23.10, with a mean value of 20.18. The genotype PYT-49 (23.10) was found highest canopy temperature followed by PYT-97(22.60), PYT-118 (22.53) and lowest temperature was found PYT-68 (18.33), PYT-23 (18.23) and PYT-101 (17.73).

Relative water content

Relative water content ranged from 67.5 to 80.3, with a mean value of 74.98. The highest RWC was found in PYT-23 (80.3), followed by PYT-27 (79.76), PYT-61 (79.60) and minimum RWC was found in PYT-40 (68.73), PYT-25 (68.26) and PYT-69 (67.5).

4.1.3 Genotypic and phenotypic coefficient of variation

In general, the values of phenotypic coefficient of variation were higher than that of genotypic coefficient of variation for all characters (Table 4.2). The phenotypic coefficient of variation was estimated to be high for ear weight (25.78%), harvest index (22.563 %), biological yield per plant (21.27%), number of ears per plant (18.01%), grain yield per plant (17.72%), number of effective tillers per plant (17.57%), peduncle length (15.79%), number of grains per plant (13.92%), ear length (11.46%), and low for number of spikelets per ear (9.31%), canopy temperature (7.77%), 1000 grain weight (7.74%), chlorophyll content (6.79%), RWC (5.45%), plant height (4.52%), days to 50% heading (4.37%), and days to maturity (2.70%).

Genotypic coefficient of variation was observed higher for ear weight (25.28%), harvest index (22.43%), biological yield per plant (21.26%), number of ears per plant (17.82%), grain yield per plant (17.65%), number of effective tillers per plant (17.45%), peduncle length (15.74%), number of grains per plant (13.92%), ear length (11.25%), and low for number of spikelets per spike (9.27%), canopy temperature (7.67%), 1000 grain weight (7.70%), chlorophyll content (6.75%), RWC (5.45%), plant height (4.53%), days to 50% heading (4.25%), and days to maturity (2.61%).

4.1.4 Heritability (bs %)

In present investigation broad sense heritability, which is the ratio of total genotypic variance to total phenotypic variance have been estimated and classified into high (>70 %), medium (50-70 %) and low (<50 %). Knowledge of heritability is of most importance for any breeding programme.

The heritability estimates for different characters are presented in table .In present investigation heritability estimates was high for biological yield per plant (99.8%), harvest index and peduncle length (99.3%), number of spikelets per spike and RWC (99.2%), number of grains per ear and 1000 grain weight (99.1%), chlorophyll content (98.8%), number of effective tillers per plant (98.6%), plant height (98.2%), number of ears per plant (97.9%), canopy temperature (97.3%), ear length (96.5%), ear weight (96.1%), days to 50% heading (94.4%), days to maturity (93.9 %).

4.1. Genetic advance as percentage of mean

The estimation of genetic advance is influenced by the unit of measurement thus to avoid this and to facilitate comparison of genetic advance of different traits genetic advance was expressed as percentage of mean. Its classes are high (>15) medium (10-15) and low (<10).

Expected genetic advance was calculated using heritability in broad sense on hypothetical basis of selection of 5% best individual plant. The estimate values for genetic advance in general exhibited higher variation from character to character.

The higher estimate of genetic advance as percent of mean was exhibited by ear weight (51.06%), harvest index (46.174%), biological yield per plant (43.76%), number of ears per plant (36.33%), grain yield per plant (36.20%), number of effective tillers per plant (35.70%), peduncle length (32.32%), number of grains per ear (28.67%), ear length (22.78%), number of spikelets per spike (19.02%), total grain weight (15.80%), canopy temperature (15.59%). The moderate estimate of genetic advance as percent of mean was exhibited by chlorophyll content (13.841%), RWC (11.224%) and low genetic advance was exhibited by plant height (9.25%), days to 50% heading (8.51%), days to maturity (5.22%).

The high heritability coupled with high genetic advance as percentage of mean (at 5% selection intensity) was recorded for ear weight, harvest index, biological yield, number of ears per plant, grain yield, number of effective tillers per plant, peduncle length, number of grains per ear, ear length, number of spikelets per spike, total grain weight and canopy temperature. The high heritability coupled with moderate genetic advance was recorded for chlorophyll content and relative water content whereas, high heritability coupled with low genetic advance was observed for plant height, days to 50% heading and days to maturity.

4.2 Association analysis

4.2.1 Correlation coefficient

The phenotypic and genotypic correlation coefficients for different pairs of character were studied and results are presented in Table 4.3 and 4.4. The correlation coefficients were tested for their significance at (n-2) degree of freedom. In general the result showed that genotypic correlation coefficients were lower than phenotypic correlation coefficient for almost all the characters under study, which were in turn higher than the environmental correlation.

The results obtained from the phenotypic correlation coefficients for different pairs of characters have been described character wise as under.

Days to 50% heading

Days to 50% flowering had highly significant positive correlation with days to maturity (0.7299), chlorophyll content (0.2959) and harvest index (0.2924). Association of days to 50% heading with other traits studied were very low in magnitude and non-significant.

Days to maturity

Days to maturity had highly significant positive correlation with grain yield per plant (0.4706), number of grains per ear (0.4467), number of spikelets per ear (0.4164), biological yield (0.3513), and 1000 grain weight (0.3121). Significant positive correlation with ear weight (0.2428). Whereas, RWC (-0.2363) had significant negative effect on days to maturity. Association of days to maturity with other traits studied were very low in magnitude and non-significant.

Plant height

Plant height had highly significant positive correlation with peduncle length (0.7973), ear weight (0.6898), ear weight (0.6668), number of spikelets per spike (0.2969) and significant positive correlation with canopy temperature (0.2258). Association of plant height with other traits studied were very low in magnitude and non-significant.

Peduncle length

Ear weight (0.8617), ear length (0.8584), number of spikelets per spike (0.5918), canopy temperature (0.3378) number of grains per ear (0.3375) had positive highly significant correlation with peduncle length. Grain yield per plant (0.2926) and biological yield (0.2305) had positive significant with peduncle length. Association of peduncle height with other traits studied was very low in magnitude and non-significant.

Ear length

Ear length had highly significant positive correlation with ear weight (0.9652), number of spikelets per spike (0.6515), number of grains per ear (0.4560), canopy temperature (0.3406) and grain yield per plant (0.3240). Harvest index (0.2309) had positive significant with ear length. Association of ear length with other traits studied were very low in magnitude and non-significant.

Ear weight

Number of spikelets per spike (0.696), number of grains per ear (0.4148), grain yield per plant (0.3318) and canopy temperature (0.3063) had positive highly significant correlation with ear weight. Harvest index (0.2193) had positive significant with ear weight. Association of ear weight with other traits studied were very low in magnitude and non-significant.

Number of effective tillers per plant

Number of effective tillers per plant had positive highly significant with number of ears per plant (0.9952) and positive significant with (0.2574). Harvest index (-0.2399) had negative significant with number of effective tillers per plant. Association of Number of effective tillers per plant with other traits studied were very low in magnitude and non-significant.

Number of ears per plant

Number of ears per plant had positive significant with biological yield (0.2619) and negative significant with harvest index (-0.2420). Association of Number of ear per plant with other traits studied were very low in magnitude and non-significant.

Number of spikelets per spike

Number of spikelets per spike had positive highly significant correlation with number of grains per ear (0.7438), grain yield per plant (0.5823), 1000 grain weight (0.5213), canopy temperature (0.4622) and biological yield (0.3741). Association of Number of spikelets per spike with other traits studied were very low in magnitude and non-significant.

Number of grains per ear

Number of grains per ear had positive highly significant correlation with grain yield per plant (0.7985), 1000 grain weight (0.6893), biological yield (0.4821) and canopy temperature (0.3230). Association of number of grains per ear with other traits studied were very low in magnitude and non-significant.

1000 grain weight

Grain yield per plant (0.8323), Harvest index (0.3624) and biological yield (0.3608) had positive highly significant correlation with 1000 grain weight. Association of 1000- grain weight with other traits studied were very low in magnitude and non-significant.

Biological yield

Grain yield per plant (0.5526) had positive highly significant correlation with biological yield and had negative highly significant with harvest index (-0.6085) and RWC (-0.3583) had negative highly significant with biological yield. Association of biological yield with other traits studied were very low in magnitude and non-significant.

Harvest index

Harvest index had positive highly significant with 1000 grain weight (0.3624), grain yield per plant (0.3002), days to 50% heading (0.2924), and positive significant with ear length (0.2309), ear weight (0.2193), and negative highly significant with biological yield ((-0.6085), and negative significant with number of ears per plant (-0.2420), number of effective tillers per plant (-0.2399). Association of harvest index with other traits studied were very low in magnitude and non-significant.

Chlorophyll content

Chlorophyll content had positive highly significant with days to 50% heading (0.2959). Association of chlorophyll content with other traits studied was very low in magnitude and non-significant.

Canopy temperature

Canopy temperature had positive highly significant with number of spikelets per spike (0.4622), ear length (0.3406), peduncle length (ear length), number of grains per ear (0.3230), ear weight (0.3063) and positive significant with plant height (0.2258). Association of canopy temperature with other traits studied was very low in magnitude and non-significant.

Relative water content

Relative water content had positive highly significant correlation with biological yield (0.3588) and negative highly significant with days to maturity (-0.2363) and negative significant with grain yield per plant (-0.2141). Associations of RWC with other traits studied were very low in magnitude and non-significant.

4.2.2 Path coefficient analysis

Path coefficients are standardized partial regression coefficients. It partition the observed correlation between dependent and independent variable in direct and indirect effects in such a manner that observed correlation between dependent and independent trait is equal to the sum of direct and all possible indirect effects.

Path coefficient analysis, which measures the direct and indirect effect of one variable through another on the end product, was carried out using genotypic as well as phenotypic correlation considering grain yield per plant as a dependable variable. The observed genotypic and phenotypic correlation coefficient on grain and its components were partitioned into direct and indirect effects and have been presented in Table 4.5 and 4.6.

In general the genotypic direct and indirect effects were higher in magnitude as compared to phenotypic direct and indirect effects. The genotypic and phenotypic direct and indirect effects followed the same

pattern. The results obtained by path coefficient analysis at genotypic level are presented under.

Direct effects

Biological yield revealed highest direct positive effect (0.9249) on grain yield followed by number of ears per plant (0.8992), harvest index (0.8695), ear length (0.3532), 1000 grain yield (0.2045), days to maturity (0.1848), chlorophyll content (0.0738), peduncle length (0.0689), canopy temperature (0.0033). However, number of effective tillers per plant (-0.8378), ear weight (-0.3400), days to 50% heading (-0.2169), plant height (-0.0816), number of grains per ear (-0.0731), RWC (-0.0547) and number of spikelets per spike (-0.0229) had direct negative effect on grain yield.

Indirect effect

Days to 50% heading

The association of days to 50% flowering with grain yield per plant was positive and small (0.0973) and it exerted positive indirect effect via RWC (0.0381), canopy temperature (0.0259) on grain yield per plant. Days to 50% flowering showed negative indirect effect via days to maturity (-0.1599), chlorophyll content (-0.0669). Other indirect effects of this trait via other characters were relatively low and negligible.

Days to maturity

Days to maturity exhibited moderate positive direct effect on grain yield per plant (0.4882). The positive indirect effect exerted on grain yield by other characters via days to 50% heading (0.1362), number of grains of ear (0.855), 1000 grain weight (0.0671), biological yield (0.0609) and negative indirect effect exerted on RWC (-0.0452), canopy temperature (-0.0051). Other indirect effects of this trait via other characters were relatively low and negligible.

Plant height

Plant height exhibited moderate positive effect on grain yield per plant (0.1053). The positive indirect effect exerted on grain yield by other characters via numbers of ears per plant (0.0140), number of effective tillers per plant

(0.0117) and negative indirect effect exerted on peduncle length (-0.0659), ear weight (-0.0583), ear length (-0.0561). Other indirect effects of this trait via other characters were relatively low and negligible

Peduncle length

The association of peduncle length with grain yield per plant was positive and small (0.2934) and it exerted positive indirect effect via ear weight (0.0610), ear length (0.0604) and negative indirect effect via number of ears per plant (-0.0137), number of effective tillers per plant (-0.0128). Other indirect effects of this trait via other characters were relatively low and negligible.

Ear length

Ear length exhibited moderate positive effect on grain yield per plant (0.3306). The positive indirect effect exerted on grain yield by other characters via ear weight (0.3484), peduncle length (0.3099), plant height (0.2428) and negative indirect effect via numbers of ears per plant (-0.0293), number of effective tillers per plant (-0.0247). Other indirect effects of this trait via other characters were relatively low and negligible.

Ear weight

The indirect effect of ear weight on grain yield per plant was positive (0.3380) and it exerted positive indirect effect via number of ears per plant (0.0308), number of effective tillers per plant (0.0256) and negative indirect effect via ear length (-0.3354), plant height (-0.2428). Other indirect effects of this trait via other characters were relatively low and negligible.

Number of effective tillers per plant

The indirect effect of Number of effective tillers per plant on grain yield per plant was positive (0.0917) and it exerted positive indirect effect via peduncle length (0.1558), harvest index (0.2045), RWC (0.1372) and negative indirect effect via number of ears per plant (-0.8379), number of grains per ear (-0.1129). Other indirect effects of this trait via other characters were relatively low and negligible.

Number of ears per plant

The indirect effect of Number of ears per plant on grain yield per plant was positive (0.0989) and it exerted positive indirect effect via number of effective tillers per plant (0.8993), biological yield (0.2376), number of grains per ear (0.1303) and negative indirect effect via harvest index (-0.2213), peduncle length (-0.1792), plant height (-0.1540). Other indirect effects of this trait via other characters were relatively low and negligible.

Number of spikelets per spike

The indirect effect of Number of effective tillers per plant on grain yield per plant was positive (0.5880) and it exerted positive indirect effect via chlorophyll content (0.0035), RWC (0.0027) and negative indirect effect via number of grains per ear (-0.0171), ear length (-0.0152). Other indirect effects of this trait via other characters were relatively low and negligible.

Number of grains per ear

The indirect effect of Number of effective tillers per plant on grain yield per plant was positive (0.8017) and it exerted positive indirect effect via RWC (0.0140) and negative indirect effect via number of spikelets per spike (-0.0546), 1000 grain weight (-0.0507). Other indirect effects of this trait via other characters were relatively low and negligible.

1000 grain weight

The indirect effect of 1000 grain weight on grain yield per plant was positive (0.8397) and it exerted positive indirect effect via harvest index (0.0745), biological yield (0.0741), days to maturity (0.0674) and negative indirect effect via chlorophyll content (-0.0200) and RWC (-0.0129).

Biological yield

The indirect effect of biological yield on grain yield per plant was positive (0.5543) and it exerted positive indirect effect via number of grains per ear (0.4463), number of spikelets per spike (0.3485), days to maturity (0.3358) and negative indirect effect via harvest index (-0.5640), RWC (-0.3318), days to 50% heading (-0.1018).

Harvest index

The indirect effect of biological yield on grain yield per plant was positive (0.2973) and it exerted positive indirect effect via 1000 grain weight (0.3166), ear length (0.2072), ear weight (0.1958) and negative indirect effect via biological yield (-0.5303), number of ears per plant (-0.2140), number of effective tillers per plant (-0.2144).

Chlorophyll content

Indirect effect of biological yield on grain yield per plant was positive (0.0013) and it exerted positive indirect effect via days to 50% heading (0.0227), plant height (0.0148), and negative indirect effect via number of spikelets per spike (-0.0114), canopy temperature (-0.0102). Other indirect effects of this trait via other characters were relatively low and negligible.

Canopy temperature

Indirect effect of biological yield on grain yield per plant was positive (0.0997) and it exerted positive indirect effect via ear length (0.0012), peduncle length (0.0011) and negative indirect effect via chlorophyll content (-0.0005). Other indirect effects of this trait via other characters were relatively low and negligible.

Relative water content

Indirect effect of biological yield on grain yield per plant was negative (-0.2149) and it exerted positive indirect effect via biological yield (0.0196), days to maturity (0.0134) and negative indirect effect via harvest index (-0.0107), ear length (-0.0071). Other indirect effects of this trait via other characters were relatively low and negligible.

4.3 Principal component analysis

Principal component analysis is a simple non parametric method for extracting relevant information from confusing data sets. With minimal efforts PCA provides a roadmap for how to reduce a complex data set to a lower dimension to sometimes hidden, simplified structures that often underlies it. Principal component analysis is appropriate for obtaining measures on a number of observed variables and to developing a smaller number of artificial

variables (called principal component) that will account for most of the variance in the observed variables. The principal component may then be used as predictor or criterion variables in subsequent analysis.

In present investigation PCA was performed for yield and yield contributing traits of bread wheat and presented in (Table 4.7, 4.8, 4.9, 4.10 and 4.11). Out of seventeen, only five principal components (PCs) exhibited more than 1.0 eigen value and showed about 68.055% variability among the traits studied. So, these five principal components were given due to importance for the further explanation. The PC1 had 24.580%, PC2 15.037%, PC3 11.049%, PC4 9.485%, PC5 showed 7.903% variability for traits under study.

Table 4.7 Eigen values, percentage of total variation and cumulative eigen values for corresponding seventeen traits

Traits	Principal Component (PC)	Eigen Value	Percentage of total Variation	Cumulative Percentage
Days to 50 % flowering	PC1	4.179	24.580	24.580
Days to maturity	PC2	2.556	15.037	39.617
Plant height	PC3	1.878	11.049	50.667
Peduncle length	PC4	1.612	9.485	60.151
Ear length	PC5	1.344	7.903	68.055
Ear weight	PC6	0.984	5.788	73.842
No. of effective tillers/plant	PC7	0.889	5.227	79.069
No. of ears/plant	PC8	0.773	4.549	83.618
No. of spikelets/spike	PC9	0.649	3.820	87.438
No. of grains/ear	PC10	0.451	2.652	90.090
Grain yield	PC11	0.406	2.391	92.421
1000 grain weight	PC12	0.354	2.081	94.562
Biological yield	PC13	0.320	1.884	96.446
Harvest index	PC14	0.258	1.521	97.967
Chlorophyll content	PC15	0.232	1.362	99.329
Canopy temperature	PC16	0.094	0.554	99.884
Relative water content	PC17	0.020	0.116	100.00

Screen plot had laid out between eigen value and principal component and showed percent of total variation between them. First principal showed highest variation 24.580% followed by 15.03% (PC2), 11.04% (PC3), 9.48% (PC4), and 7.90% (PC5). Total variation of five PCs was recorded 68.005%. The maximum variation was found in first PC; therefore selection from this PC may be desirable.

Rotated component matrix revealed that the first principal component which accounted for highest variation (24.580%) was mostly related with traits such as number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, grain yield, plant height and 1000 grain weight. In second principal component the traits viz., number of ears per plant and number of effective tillers per plant were more related. In third principal component the traits viz., Biological yield and canopy temperature were more related. Fourth principal component was more related with days to 50% flowering, days to maturity, and chlorophyll content. Fifth principal component was more related with harvest index and relative water content.

Table 4.8 Principal components for 17 yield contributing traits of wheat

Rotated Component Matrix					
Traits	Principal Component				
	1	2	3	4	5
Days to 50 % flowering	0.10	0.16	-0.31	0.78	0.10
Days to Maturity	0.39	0.32	-0.26	0.56	-0.16
Plant height	0.53	-0.43	0.15	0.25	-0.01
Peduncle length	0.75	-0.38	0.23	0.08	-0.09
Ear length	0.77	-0.34	0.31	0.09	0.11
Ear weight	0.75	-0.38	0.26	0.12	0.08
No. of effective tillers/plant	0.10	0.66	0.64	0.16	0.31
No. of ears/plant	0.39	0.68	0.62	0.14	0.31
No. of spikelets/spike	0.78	0.12	0.01	-0.07	0.02
No. of grains/ear	0.67	0.42	-0.16	-0.21	0.03
Grain yield	0.59	0.47	-0.36	-0.20	0.02
1000 grain weight	0.53	0.34	-0.38	-0.27	0.14
Biological yield	0.35	0.12	0.44	-0.08	-0.63
Harvest index(%)	0.17	0.009	-0.51	-0.02	0.68
Chlorophyll content	-0.05	-0.12	-0.21	0.47	-0.09
Canopy temperature	0.37	-0.13	0.39	-0.35	-0.02
Relative water content	-0.05	-0.38	0.08	-0.11	0.42

PC scores of genotypes

In 30 wheat genotypes, top ten principal component scores (PC score) for all the traits were estimated in this five components and presented in (Table 4.9, 4.10 and 4.11). These score utilized to propose precise selection indices whose intensity can be decided by variability explained by each of principal component. High PC score for a particular genotype in a particular component denotes high values for the variables in that particular genotypes. PC score table revealed that genotype PYT-49 had highest PC score followed by PYT-40, PYT-104, PYT-118, PYT-60, PYT-22, PYT-122, PYT-16, PYT-97, PYT-61, PYT-51, PYT-115, PYT-27 and PYT-120 in PC1 and indicated that they had highly and positively associated for the characters contributed for yield traits as viz., number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, grain yield, plant height and 1000 grain weight. The highest PC score of PYT-69, followed by PYT-101, PYT-115, PYT-57, PYT-68, PYT-51, PYT-58, PYT-61, PYT-97, PYT-40, PYT-47 and PYT-89 in PC2 exhibited for character viz., number of ears per plant and number of effective tillers per plant were more related.

Table 4.9 Interpretation of rotated component matrix for the traits having highest value in each PCs

PC1	PC2	PC3	PC4	PC5
No. of spikelets/spike	No. of ears/plant	Biological yield	Days to 50% flowering	Harvest index
Ear length	No. of effective tillers/plant	Canopy temperature	Days to maturity	Relative water content
Ear weight			Chlorophyll content	
Peduncle length				
No. of grains/ear				
Grain yield				
Plant height				
1000 grain weight				

Similarly PYT-97, PYT-89, PYT-40, PYT-101, PYT-21, PYT-58, PYT-51, PYT-49, PYT-61, PYT-66 and PYT-6 in PC3 for character like biological yield and canopy temperature were more related. PC scores in PC4 were recorded highest for PYT-49, PYT-115, PYT-47, PYT-101, PYT-66, PYT-23, PYT-27, PYT-16 and PYT-22 for character like days to 50% flowering, days to maturity, and chlorophyll content. PYT-27 had highest PC scores followed by PYT-6, PYT-16, PYT-60, PYT-22, PYT-24, PYT-23 and PYT-101 in PC5 for harvest index and relative water content.

Table 4.10 Principal Component Score

Genotype	PC1 Score	PC2 Score	PC3 Score	PC4 Score	PC5 Score
PYT-2	-4.212	-2.312	0.404	-0.227	-0.419
PYT-6	-0.946	-1.204	0.615	-0.266	-0.962
PYT-16	1.687	-0.840	-0.665	0.972	1.697
PYT-21	-3.006	-1.053	1.543	-1.767	-0.017
PYT-22	2.313	-1.715	-0.742	0.593	1.579
PYT-23	-3.173	0.096	0.435	1.494	1.293
PYT-24	-3.762	-1.051	0.133	0.489	1.517
PYT-25	-2.959	-2.524	-1.319	0.094	-0.726
PYT-27	0.617	-2.379	-3.156	1.453	2.768
PYT-40	3.648	0.654	1.805	-1.654	-0.336
PYT-46	0.460	-2.811	0.360	-0.479	-0.849
PYT-47	-1.926	0.651	0.381	2.217	-1.260
PYT-49	4.203	-0.675	0.988	2.272	-2.048
PYT-51	0.713	1.737	1.288	-1.033	0.178
PYT-57	-1.528	2.364	-2.090	-0.641	-0.932
PYT-58	-3.517	1.371	1.439	-0.491	-0.455
PYT-60	2.407	-0.046	-2.555	-0.505	1.631
PYT-61	1.531	1.003	0.899	-1.105	2.607
PYT-66	0.413	-1.077	0.849	1.593	0.194
PYT-68	-0.308	2.160	-1.581	-0.310	-1.020
PYT-69	-0.187	4.010	-2.408	-1.128	-0.497
PYT-89	-0.488	0.525	1.840	0.141	0.466
PYT-97	1.673	0.837	2.035	-1.290	0.402
PYT-101	-1.348	2.886	1.175	1.773	0.503
PYT-104	2.970	0.423	-1.113	0.377	-1.584
PYT-109	-1.422	-0.614	-0.774	-2.957	-0.572
PYT-115	0.639	2.739	0.339	2.268	-1.017
PYT-118	2.840	-0.321	-0.007	0.024	-0.007
PYT-120	0.574	-1.202	-1.569	-0.028	-1.425
PYT-122	2.094	-1.629	1.452	-1.880	-0.711

Summarized form of genotypes were presented in Table 4.11 based on top ten PC scores.

Table 4.11 List of selected genotype in each principal component

PC1	PC2	PC3	PC4	PC5
PYT- 49	PYT- 69	PYT- 97	PYT- 49	PYT- 27
PYT- 40	PYT-101	PYT- 89	PYT-115	PYT- 61
PYT-104	PYT-115	PYT- 40	PYT- 47	PYT- 16
PYT-118	PYT- 57	PYT- 21	PYT-101	PYT- 60
PYT- 60	PYT- 68	PYT- 58	PYT- 66	PYT- 22
PYT- 22	PYT- 51	PYT- 51	PYT- 23	PYT- 24
PYT-122	PYT- 58	PYT-101	PYT- 27	PYT- 23
PYT-16	PYT- 61	PYT- 49	PYT- 16	PYT-101
PYT- 97	PYT- 97	PYT- 61	PYT- 22	
PYT- 61	PYT- 40	PYT- 66		
PYT- 51	PYT- 47	PYT- 6		
PYT-115	PYT- 89			
PYT- 27				
PYT-120				

DISCUSSION

India is the second largest producer of wheat and Uttar Pradesh, Madhya Pradesh and Punjab are important states from the point of both area and production of wheat. The reason of low productivity is high temperature during early vegetative phase. Water availability is one of the another factors limiting wheat productivity because water stress not only affects the morphology but also severely affects the metabolism of the plant. There is no real rainfed area in M.P. Rainfed area is converted to partially irrigated where one or two irrigations can be made.

Keeping that in view the present investigation entitled “Genetic Studies of Wheat Genotypes under Restricted Irrigated condition” was carried out under wheat improvement project at Seed Breeding Farm in College of Agriculture, Jabalpur during the *Rabi* season of 2015-2016 with the following heads:

5.1 Parameters of genetic variability

5.1.1 Genetic variability

5.1.2 Genotypic and phenotypic coefficient of variation

5.1.3 Heritability and genetic advance

5.2 Correlation coefficient analysis

5.3 Path coefficient analysis

5.4 Principal component analysis

The field observations were recorded for days to 50 % heading, days to maturity, plant height, peduncle length, ear length, ear weight, number of ears/plant, number of spikelets per spike, number of grains per ear, 1000-grain weight, grain yield, biological yield, harvesting index, chlorophyll content, canopy temperature and relative water content.

In the present study 30 wheat genotypes were taken up with the aim to evaluate them for yield and its contributing traits under restricted irrigation. These include parameters of genetic variability, nature and extent of character association at genotypic and phenotypic level and path coefficient analysis.

The discussion of the results of present investigations is present below with reference to the available literature.

5.1 Parameters of genetic variability

5.1.1 Genetic variability

The mean sum of squares due to genotypes were highly significant for all the traits under study viz., days to 50% flowering, days to maturity, plant height, number of effective tillers, number of ears per plant, number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, 1000-grain weight, grain yield per plant, biological yield per plant. This indicates that substantial variability has been created and genetic base is broadened for most of the important traits among different genotypes developed through hybridization involving diverse parents. The exploitation of the present variability may lead to development of potential and suitable genotypes in future.

Similar results had been reported by Pawar et al. (2002) for days to 50% heading, plant height, number of tillers per plant, length of ear, number of spikelets per spike, number of grains per ear, 1000 grain weight and grain yield.

Kalimullah et al. (2012) observed variability for number of grains per spike, number of tillers per plant, 1000-grain weight and grain yield per plant.

5.1.2 Genotypic and phenotypic coefficient of variation

To obtain a clear picture about the variability in all the genotypes, the variability was further splitted into phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV). In general the values of phenotypic coefficient of variation were higher than that of genotypic coefficient of variation for all characters. The phenotypic and genotypic coefficients of variation was estimated to be high for ear weight, harvest index, biological yield per plant, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, number of grains per plant, ear length. However, low phenotypic and genotypic coefficients of variation were observed for number of spikelets per spike, canopy temperature, 1000- grain

weight, chlorophyll content, RWC, plant height, days to 50% heading and days to maturity.

The results found in present investigation were in agreement with the low differences between the phenotypic and genotypic coefficients of variations (Majumdar et al., 2008, Al-Otayk, 2010), green leaf area duration, height, plant type, heading and maturity dates, and yield potential (Babar et al., 2006).

The present findings are in contradiction with Ali et al. (2008), Ali and Shakor (2011), Al-Tabbal and Al-Fraihat (2012), Talebi and Fayyaz (2012), Baloch et al. (2013), Singh and Upadhyay (2013), Haman (2013), Shukla and Moitra (2013), Bala et al. (2014), Dharmendra and Singh (2015) observed high genotypic and phenotypic coefficients of variation for Plant height, number of productive tillers per plant, number of spikelets per spike, spike length, number of grains per spike, fertility %, 1000 grain weight.

Heritability and genetic advance

The coefficient of variation indicates only the extent of variability present in the characters that does not indicate the heritable portion. This could be ascertained from heritability estimates. Phenotypic variation in the population is the result of genotypic and environmental effects. The portion of total variation caused by genotypes is called heritability and estimated as the ratio of genotypic variance to the total phenotypic variance. Broad sense heritability includes both additive and non additive gene effects. The knowledge of heritability is helpful in assessing merits and demerits of a particular trait as it enables the plant breeder to decide the course of selection procedures to be followed under a given situation.

High heritability estimate coupled with high genetic advance as percent of mean was exhibited by ear weight, harvest index, biological yield per plant, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, number of grains per ear, ear length, number of spikelets per spike, total grain weight, canopy temperature. Such results indicate chances of improving these traits through simple selection. The moderate estimate of genetic advance as percent of mean was exhibited by

chlorophyll content, RWC and low genetic advance was exhibited by plant height, days to 50% heading, days to maturity. This reflects the presence of non-additive gene effects.

High heritability with high genetic advance was obtained for number of productive tillers per plant, plant height, number of spikelets per spike, spike length, number of grains per spike, 1000- grain weight and yield per plant. These results are in agreement with the findings of Dwivedi et al. (2002), Kumar and Mishra (2004), Memon et al. (2007) and Majumder et al. (2008). Similarly, high heritability with low genetic advance reported by Baranwal et al. (2012) for days to 50% heading.

Contradictory results have also been reported by Aycicek and Yildirim (2006) and Yadav et al. (2011) who reported lowest heritability for number of grains per ear, grain yield, spike number per square meter, plant height, grain number per spike, grain weight per spike, 1000- kernel weight and days to heading.

5.2 Correlation coefficient analysis

Correlation studies provide information on the nature and extent of association between any two pairs of metric characters correlation between any two pairs of traits due to genotypic and environmental causes. Grain yield is the end product of interactions of many factors known as contributing components hence it is complex traits. Understanding of the interaction of characters among themselves and with the environment has been of great use in the plant breeding, genotypic correlation between different characters of plant could arise because of linkage relationship.

In general, the genotypic correlation coefficient values were higher than the phenotypic values. This indicated that how much of phenotypic correlation coefficient are influenced by environment. In the present study, all possible correlation coefficient at genotypic and phenotypic levels among 16 traits themselves and with grain yield/plant were estimated. The phenotypic correlation coefficient has been discussed here:

In present investigation the grain yield per plant was positively and significantly associated with 1000 grain weight, number of grains per ear,

number of spikelets per spike, biological yield, days to maturity, ear weight, ear length, harvest index, peduncle length,

The results found in present investigation were agreement with Ali et al. (2008). Kahrizi et al. (2010) were found high correlations among the plant height, leaf dry weight, stem dry weight, spike dry weigh, Mohibullah et al. (2011) were found spike length showed positive significant correlation with number of spikelets per spike and grain yield per plant.

Whereas, plant height, canopy temperature, numbers of ears per plant, number of effective tillers per plant, days to 50% heading, and chlorophyll content had showed positive non-significant, and RWC had showed negative non-significant on grain yield.

The present findings are in contradiction with Kashif and Khaliq (2004), Ali et al (2008), Dharmendra and Singh (2015) who observed that grain yield per plant showed highly significant positive correlation with number of productive tillers per plant, number of spikelets per spike and number of grains per spike and significant positive correlation with spike length.

5.3 Path coefficient analysis:

The correlation coefficient between characters exhibits the relationship existing between pairs of characters. But, a dependent character is an interaction of product of many mutually associated component characters and change in any one component will disturb whole network of cause and effect system.

The path coefficient analysis, a statistical device developed by Wright (1921), which takes into account the cause and effect relationship between the variables. The path coefficient partition the association into direct and indirect effects via other the relative importance of causal factors involved. This is simply standardized regression analysis. Path diagram facilitates the understanding the nature of cause and effect system. The path analysis suggested by Dewey and Lu (1959) helps to resolve these correlations further and lighter on the way in which component traits contribute towards specifically identifying important traits.

In the present investigations path coefficient analysis has been performed at genotypic and phenotypic levels taking yield as a dependent variable. In general genotypic direct and indirect effects were slightly higher in magnitude as compared to the phenotypic effects.

Biological yield revealed highest direct effect on grain yield followed by number of ears per plant, harvest index, ear length, 1000-grain weight, days to maturity, canopy temperature, peduncle length, canopy temperature. However, number of spikelets per spike, RWC, number of grains per ear, plant height, days to 50% heading, ear weight, and number of effective tillers per plant had negative direct effect on grain yield.

The results found in present investigation were in agreement with the findings of (Khokhar et al., 2009) where they observed that the highest positive direct effect on yield were exhibited by days to maturity followed by days to heading.

Fikre et al. (2015) studied sixty four bread wheat genotypes and observed that grain weight, spike length, number of grains per plant and number of spikelets per spike had positive direct effects on grain yield.

Majority of indirect effects of various independent traits via other traits were extremely low of either signs. There were only few characters which had higher to moderate positive indirect effects. The indirect effects of 1000- grain weight, number of spikelets per spike, biological yield, days to maturity, ear weight, ear length, harvest index, peduncle length. Hence these indirect effects should also be kept in mind while selection for better yield.

5.4 Principal component analysis

Principal component analysis has wide spread applications because it reveals simple underlying structures in complex data sets using analytical solution. Principal component analysis provides a means for comparing relative importance of such dimensions. Principal component analysis was performed for identification and ranking of genotypes based on combination of phenotypic traits.

In the present investigation PCA was performed for yield and yield contributing traits of bread wheat. Out of twenty only five principal

components (PCs) exhibited more than 1.0 eigen value, and showed about 68.055% variability among the traits studied. So, these five principal components were given due importance for further explanation. The PC1 had 24.580%, PC2 15.037%, PC3 11.049%, PC4 9.485%, PC5 showed 7.903% variability for traits under study. The first principal component which accounted for highest variation was mostly related to traits like number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, grain yield, plant height and 1000- grain weight. In second principal component the traits viz., number of ears per plant and number of effective tillers per plant were more related. In the third principal component the traits viz., biological yield and canopy temperature were more related. Fourth principal component was more related with days to 50% flowering, days to maturity, and chlorophyll content. Fifth principal component was more related to harvest index and relative water content.

The results found in present investigation were in agreement with the findings of (Sajjid et al. 2011) who reported that the number of kernels per plant, number of spikes per plant, spike dry weight contributes toward significant principal component and were highly related to grain yield.

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

6.1 Summary

The present investigation entitled “Genetic Studies of Wheat Genotypes under Restricted Irrigated Condition” was carried out under Wheat Improvement Project at Seed Breeding Farm in Department of Plant Breeding and Genetics, JNKVV, Jabalpur during *Rabi* season 2015-16. The experimental materials were planted in Randomized Block Design with three replications. This investigation was carried out to estimate the genetic variability, heritability, genetic advance, correlation coefficient, path coefficient analysis and principal component analysis between yield and yield contributing trait and formulating selection criteria for improvement in yield under restricted irrigated condition.

Five competitive plants were randomly selected from each replication and observations were recorded on 17 traits viz., days to 50% heading, days to maturity, peduncle length, plant height, ear length, ear weight, number of effective tillers per plant, number of ears per plant, number of spikelets per spike, grain yield, 1000-grain weight, biological yield, harvest index, chlorophyll content, canopy temperature, and RWC. On the basis of findings, the present investigation was summarized as follows:

The analysis of variance revealed highly significant differences for all the characters. It indicated the existence of sufficient genetic variability for the traits studies. The phenotypic and genotypic coefficient of variation was estimated to be high for ear weight, harvest index, biological yield per plant, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, number of grains per plant, ear length and low for number of spikelets per spike, canopy temperature, 1000- grain weight, chlorophyll content, RWC, plant height, days to 50% heading, and days to maturity.

On the basis of performance of different genotypes of advance generation, out of 30 genotypes PYT-57, PYT-60, PYT-104, PYT-40 and PYT-69 were recorded high grain yield.

High heritability estimate coupled with high genetic advance as percent of mean was exhibited by ear weight, harvest index, biological yield per plant, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, number of grains per ear, ear length, number of spikelets per spike, total grain weight, canopy temperature. The moderate estimate of genetic advance as percent of mean was exhibited by chlorophyll content, RWC and low genetic advance was exhibited by plant height, days to 50% heading, days to maturity.

Grain yield per plant was positively and significantly associated with 1000-grain weight, number of grains per ear, number of spikelets per spike, biological yield, days to maturity, ear weight, ear length, harvest index, peduncle length, whereas, plant height, canopy temperature, numbers of ears per plant, number of effective tillers per plant, days to 50% heading, and chlorophyll content had showed positive non-significant, and RWC had showed negative non-significant on grain yield.

Path coefficient analysis, which measures the direct and indirect effect of one variable through another on the end product, was carried out using genotypic as well as phenotypic correlation considering grain yield per plant as a dependable variable. Biological yield revealed highest direct positive effect on grain yield followed by number of ears per plant, harvest index, ear length, 1000-grain weight, days to maturity, canopy temperature, peduncle length, canopy temperature. However, number of spikelets per spike, RWC, number of grains per ear, plant height, days to 50% heading, ear weight, and number of effective tillers per plant exerted high negative direct effect on grain yield.

Out of twenty, only five principal components (PCs) exhibited more than 1.0 eigen value and showed about 68.055% variability among the traits studied. So, these five principal components were given due to importance for

the further explanation. The PC1 had 24.580%, PC2 15.037%, PC3 11.049%, PC4 9.485%, PC5 showed 7.903% variability for traits under study.

Rotated component matrix revealed that the first principal component which accounted for highest variation (24.58%) was mostly related with traits such as number of spikelets per spike, ear length, ear weight, peduncle length, number of grains per ear, grain yield, plant height and 1000-grain weight. In second principal component the traits *viz.*, number of ears per plant and number of effective tillers per plant were more related. In third principal component the traits *viz.*, biological yield and canopy temperature were more related. Fourth principal component was more related with days to 50% flowering, days to maturity and chlorophyll content. Fifth principal component was more related with harvest index and relative water content.

The PC scores of each component (PC1, PC2, PC3, PC4 and PC5) had positive and negative values. Germplasm lines showing maximum positive PC scores and common in maximum PCs which are mostly related with yield and quality traits are PYT-61, PYT-101, PYT-22, PYT-49, PYT-40, PYT-16, PYT-97, PYT-51, PYT-115 and PYT-27.

Thus, selection of these lines can help in further development of high yielding varieties of wheat.

6.2 Conclusion

1. Substantial genetic variability was depicted by most of the traits under study, which indicated that the genetic base had been broadened in recently developed genotypes. Hence, further utilization of these genotypes in hybridization programme may generate potential future pre-breeding lines/cultivars of wheat.
2. High phenotypic and genotypic coefficient of variation was estimated for ear weight, harvest index and biological yield per plant indicating greater diversity for these traits and their further improvement through selection.
3. High heritability coupled with high genetic advance was found for ear weight, harvest index, biological yield per plant, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, number of grains per ear, ear length, number of spikelets per spike,

thousand grain weight and canopy temperature. It indicates contribution of additive gene effects and selection for such traits may be rewarding.

4. Correlation and path analysis revealed that the traits are *viz.*, biological yield, number of ears per plant and harvest index should find due importance while mounting the selection to achieve superior genotypes.
5. In principal component analysis characters contributed for yield can be highlighted by PC1, PC2 and PC3. Whereas, characters for maturity can be expressed by PC4 and physiological traits can be included in PC5.
6. On the basis of principal component analysis 5 principal components (PCs) showed about 68.05% variability and germplasm *viz.*, PYT-61, PYT-101, PYT-22, PYT-49, PYT-40, PYT-16, PYT-97, PYT-51, PYT-115 and PYT-27 had been identified as promising genotypes as they possess higher values for yield and yield attributing related traits

6.3 Suggestions for further work

1. To isolate potential genotypes important morphological traits should be given due importance in hybridization and selection programmes along with economic trait.
2. Characters *viz.*, Ear weight, harvest index, number of ears per plant, grain yield per plant, number of effective tillers per plant, peduncle length, ear length, showing high heritability coupled with high genetic advance should be exploited to develop better plant ideotype of wheat using the findings of correlation and path analysis.
3. Further research with molecular characterization of above identified promising wheat germplasm lines to provide more accurate measures of genetic diversity should be done.

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**Table 3.1 Weekly Meteorological data during *Rabi* season, 2015-2016 at Jabalpur (Madhya Pradesh)
(October 2015 – May 2016)**

S. No.	Dates	Standard weeks	Temperature (°C)		RH (%)		Wind Velocity (Km/hrs .)	Sunshine (hrs.)	Rainfall (mm)	No. of rainy Days
			Max.	Min.	Mor.	Even.				
1	8-14 Oct.	41	35.1	17.9	88.0	31.0	2.2	09.5	00.0	00
2	15-21 Oct.	42	34.0	19.0	86.0	36.0	2.4	09.2	00.0	00
3	22-28 Oct.	43	33.3	18.4	87.0	47.0	2.6	06.9	00.0	00
4	29-4 Nov.	44	28.0	17.0	92.0	58.0	4.1	05.8	40.0	01
5	5-11 Nov.	45	31.4	17.9	88.0	40.0	1.8	05.8	00.0	00
6	12-18 Nov.	46	30.0	14.1	89.0	35.0	1.6	07.6	00.0	00
7	19-25 Nov.	47	29.0	12.7	89.0	36.0	1.7	06.7	00.0	00
8	26-2 Dec.	48	30.8	14.5	88.0	34.0	2.3	07.2	00.0	00
9	3-9 Dec	49	28.1	09.2	92.0	30.0	2.0	07.8	00.0	00
10	10-16 Dec	50	26.6	09.2	82.0	32.0	3.0	07.6	00.0	00
11	17-23 Dec	51	24.1	07.0	86.0	37.0	2.8	07.0	00.0	00
12	24-31 Dec	52	24.2	05.4	91.0	25.0	1.5	08.6	00.0	00
13	1-7 Jan.	1	27.5	07.9	88.0	27.0	1.8	08.5	00.0	00
14	8-14 Jan.	2	26.7	08.0	81.0	32.0	1.7	07.7	00.0	00
15	15-21 Jan.	3	22.2	11.5	92.0	65.0	3.5	05.4	12.2	02
16	22-28 Jan.	4	23.3	04.2	94.0	29.0	2.3	09.6	00.0	00
17	29-4 Feb.	5	27.7	09.3	92.0	35.0	2.8	09.3	00.0	00
18	5-11 Feb	6	26.4	08.4	84.0	34.0	3.2	08.3	00.0	00
19.	12-18 Feb.	7	28.5	11.3	88.0	47.0	3.3	06.9	00.0	00
20.	19-25 Feb.	8	30.2	11.8	90.0	32.0	2.7	07.4	00.0	00
21.	26-4 Mar.	9	30.5	13.4	97.0	39.0	3.3	08.5	00.0	00
22.	5-11 Mar.	10	31.9	17.0	88.0	47.0	3.5	08.0	29.6	02
23.	12-18 Mar.	11	30.9	15.9	85.0	37.9	4.1	08.7	06.5	02
24.	19-25 Mar.	12	34.5	14.1	67.1	18.0	3.3	10.2	00.0	00
25.	26-1 Apr.	13	35.8	16.4	78.3	17.6	2.3	10.0	08.0	01
26.	2-8 Apr.	14	39.1	20.1	62.3	18.4	3.0	09.1	00.0	00
27.	9-15 Apr.	15	38.9	19.6	56.3	12.3	3.8	10.2	00.0	00
28.	16-22 Apr.	16	41.1	21.9	48.2	12.4	5.0	10.5	00.0	00
29.	23-29 Apr.	17	40.2	20.9	46.0	11.0	5.1	10.4	00.0	00
30	30-6 May	18	41.5	22.7	38.0	14.0	6.9	09.8	03.2	01

Table 4.2 Parameters of genetic variability for phenological and yield contributing traits

S. No.	Traits	Range		Mean	Coefficient of variation		$h^2(bs\%)$	Genetic Advance	Genetic Advance as % of Mean
		Min.	Max.		GCV (%)	PCV (%)			
1	DFF	69.66	82.66	76.65	4.25	4.37	94.4	6.52	8.51
2	DM	116.33	127.66	122.23	2.61	2.70	93.9	6.38	5.22
3	PH	87.43	108.60	97.70	4.53	4.52	98.2	9.03	9.25
4	PL	11.86	21.00	16.42	15.74	15.79	99.3	5.31	32.32
5	EL	9.00	13.10	10.93	11.25	11.46	96.5	2.49	22.78
6	EW	1.80	4.26	2.94	25.28	25.78	96.1	1.50	51.06
7	NETP	4.46	8.70	6.29	17.45	17.57	98.6	2.24	35.70
8	NEPP	4.36	8.66	6.21	17.82	18.01	97.9	2.25	36.33
9	NSPE	12.73	17.50	14.94	9.27	9.31	99.2	2.88	19.02
10	NGPE	32.63	52.93	44.74	13.92	13.92	99.1	12.82	28.67
11	TGW	35.33	46.06	40.61	7.70	7.74	99.1	6.42	15.80
12	BYPP	20.36	46.80	35.11	21.26	21.27	99.8	15.36	43.76
13	HI	19.90	46.23	27.16	22.48	22.56	99.3	12.54	46.17
14	GYPP	5.83	11.60	9.27	17.65	17.72	99.1	3.35	36.20
15	CC	37.60	46.36	42.07	6.75	6.79	98.8	5.82	13.84
16	CT	17.73	23.10	20.18	7.67	7.77	97.3	3.14	15.59
17	RWC	67.50	80.30	74.98	5.45	5.45	9.2	8.41	11.22

** Significant at 1% *Significant at 5%

DFF-Days to 50% flowering, DM-Days to maturity, PH-Plant height, PL-Peduncle length, EL- Ear length, EW- Ear weight, NETP-Number of effective tillers per plant, NEPP-Number of ears per plant, NSPS-Number of spikelets per spike, NGPE-Number of grains per ear, TGW-Thousand grain weight, BYPP-Biological yield per plant, HI-Harvest index, GYPP-Grain yield per plant, CC-Chlorophyll content, CT-Canopy temperature, RWC-Relative water content.

APPENDIX

Weekly Meteorological data during *Rabi* season, 2015-2016 at Jabalpur (Madhya Pradesh) (October 2015 – May 2016)

S. No.	Dates	Standard weeks	Temperature (°C)		RH (%)		Wind Velocity (Km/hrs.)	Sunshine (hrs.)	Rainfall (mm)	No. of rainy Days	Vapour Pressure (mm)		Evaporation (mm)
			Max.	Min.	Mor.	Even.					Mor.	Eve.	
1	8-14 Oct.	41	35.1	17.9	88.0	31.0	2.2	09.5	00.0	00	16.3	12.2	03.8
2	15-21 Oct.	42	34.0	19.0	86.0	36.0	2.4	09.2	00.0	00	17.0	14.1	03.7
3	22-28 Oct.	43	33.3	18.4	87.0	47.0	2.6	06.9	00.0	00	16.6	15.0	03.0
4	29-4 Nov.	44	28.0	17.0	92.0	58.0	4.1	05.8	40.0	01	15.5	16.2	01.7
5	5-11 Nov.	45	31.4	17.9	88.0	40.0	1.8	05.8	00.0	00	15.2	13.5	02.7
6	12-18 Nov.	46	30.0	14.1	89.0	35.0	1.6	07.6	00.0	00	12.2	11.3	02.5
7	19-25 Nov.	47	29.0	12.7	89.0	36.0	1.7	06.7	00.0	00	11.5	10.7	02.3
8	26-2 Dec.	48	30.8	14.5	88.0	34.0	2.3	07.2	00.0	00	12.4	11.3	02.4
9	3-9 Dec	49	28.1	09.2	92.0	30.0	2.0	07.8	00.0	00	09.4	08.3	02.1
10	10-16 Dec	50	26.6	09.2	82.0	32.0	3.0	07.6	00.0	00	08.4	08.0	02.3
11	17-23 Dec	51	24.1	07.0	86.0	37.0	2.8	07.0	00.0	00	07.3	08.1	02.0
12	24-31 Dec	52	24.2	05.4	91.0	25.0	1.5	08.6	00.0	00	07.0	05.8	02.0
13	1-7 Jan.	1	27.5	07.9	88.0	27.0	1.8	08.5	00.0	00	08.0	07.4	01.8
14	8-14 Jan.	2	26.7	08.0	81.0	32.0	1.7	07.7	00.0	00	07.6	08.0	02.1
15	15-21 Jan.	3	22.2	11.5	92.0	65.0	3.5	05.4	12.2	02	10.6	11.8	01.3
16	22-28 Jan.	4	23.3	04.2	94.0	29.0	2.3	09.6	00.0	00	06.4	06.7	01.9
17	29-4 Feb.	5	27.7	09.3	92.0	35.0	2.8	09.3	00.0	00	08.9	09.3	02.5
18	5-11 Feb	6	26.4	08.4	84.0	34.0	3.2	08.3	00.0	00	08.1	08.9	02.8
19.	12-18 Feb.	7	28.5	11.3	88.0	47.0	3.3	06.9	00.0	00	10.5	11.4	02.6
20.	19-25 Feb.	8	30.2	11.8	90.0	32.0	2.7	07.4	00.0	00	11.0	11.5	03.0
21.	26-4 Mar.	9	30.5	13.4	97.0	39.0	3.3	08.5	00.0	00	10.7	11.0	02.8
22.	5-11 Mar.	10	31.9	17.0	88.0	47.0	3.5	08.0	29.6	02	14.1	15.3	03.4
23.	12-18 Mar.	11	30.9	15.9	85.0	37.9	4.1	08.7	06.5	02	13.0	11.2	03.9
24.	19-25 Mar.	12	34.5	14.1	67.1	18.0	3.3	10.2	00.0	00	10.5	07.3	05.3
25.	26-1 Apr.	13	35.8	16.4	78.3	17.6	2.3	10.0	08.0	01	12.9	07.1	04.7
26.	2-8 Apr.	14	39.1	20.1	62.3	18.4	3.0	09.1	00.0	00	13.6	09.1	06.5
27.	9-15 Apr.	15	38.9	19.6	56.3	12.3	3.8	10.2	00.0	00	12.2	06.5	07.7
28.	16-22 Apr.	16	41.1	21.9	48.2	12.4	5.0	10.5	00.0	00	11.7	07.1	08.8
29.	23-29 Apr.	17	40.2	20.9	46.0	11.0	5.1	10.4	00.0	00	11.6	06.2	09.4
30	30-6 May	18	41.5	22.7	38.0	14.0	6.9	09.8	03.2	01	10.9	07.8	10.7

**Appendix I: Weekly Meteorological data during *Rabi* season, 2015-2016 at Jabalpur (Madhya Pradesh)
(October 2015 – May 2016)**

S. No.	Dates	Standard weeks	Temperature (°C)		RH (%)		Wind Velocity (Km/hrs.)	Sunshine (hrs.)	Rainfall (mm)	No. of rainy Days	Vapour Pressure (mm)		Evaporation (mm)
			Max.	Min.	Mor.	Even.					Mor.	Eve.	
1	8-14 Oct.	41	35.1	17.9	88.0	31.0	2.2	09.5	00.0	00	16.3	12.2	03.8
2	15-21 Oct.	42	34.0	19.0	86.0	36.0	2.4	09.2	00.0	00	17.0	14.1	03.7
3	22-28 Oct.	43	33.3	18.4	87.0	47.0	2.6	06.9	00.0	00	16.6	15.0	03.0
4	29-.4 Nov.	44	28.0	17.0	92.0	58.0	4.1	05.8	40.0	01	15.5	16.2	01.7
5	5-11 Nov.	45	31.4	17.9	88.0	40.0	1.8	05.8	00.0	00	15.2	13.5	02.7
6	12-18 Nov.	46	30.0	14.1	89.0	35.0	1.6	07.6	00.0	00	12.2	11.3	02.5
7	19-25 Nov.	47	29.0	12.7	89.0	36.0	1.7	06.7	00.0	00	11.5	10.7	02.3
8	26-2 Dec.	48	30.8	14.5	88.0	34.0	2.3	07.2	00.0	00	12.4	11.3	02.4
9	3-9 Dec	49	28.1	09.2	92.0	30.0	2.0	07.8	00.0	00	09.4	08.3	02.1
10	10-16 Dec	50	26.6	09.2	82.0	32.0	3.0	07.6	00.0	00	08.4	08.0	02.3
11	17-23 Dec	51	24.1	07.0	86.0	37.0	2.8	07.0	00.0	00	07.3	08.1	02.0
12	24-31 Dec	52	24.2	05.4	91.0	25.0	1.5	08.6	00.0	00	07.0	05.8	02.0
13	1-7 Jan.	1	27.5	07.9	88.0	27.0	1.8	08.5	00.0	00	08.0	07.4	01.8
14	8-14 Jan.	2	26.7	08.0	81.0	32.0	1.7	07.7	00.0	00	07.6	08.0	02.1
15	15-21 Jan.	3	22.2	11.5	92.0	65.0	3.5	05.4	12.2	02	10.6	11.8	01.3
16	22-28 Jan.	4	23.3	04.2	94.0	29.0	2.3	09.6	00.0	00	06.4	06.7	01.9
17	29-4 Feb.	5	27.7	09.3	92.0	35.0	2.8	09.3	00.0	00	08.9	09.3	02.5
18	5-11 Feb	6	26.4	08.4	84.0	34.0	3.2	08.3	00.0	00	08.1	08.9	02.8
19.	12-18 Feb.	7	28.5	11.3	88.0	47.0	3.3	06.9	00.0	00	10.5	11.4	02.6
20.	19-25 Feb.	8	30.2	11.8	90.0	32.0	2.7	07.4	00.0	00	11.0	11.5	03.0
21.	26-4 Mar.	9	30.5	13.4	97.0	39.0	3.3	08.5	00.0	00	10.7	11.0	02.8
22.	5-11 Mar.	10	31.9	17.0	88.0	47.0	3.5	08.0	29.6	02	14.1	15.3	03.4
23.	12-18 Mar.	11	30.9	15.9	85.0	37.9	4.1	08.7	06.5	02	13.0	11.2	03.9
24.	19-25 Mar.	12	34.5	14.1	67.1	18.0	3.3	10.2	00.0	00	10.5	07.3	05.3
25.	26-1 Apr.	13	35.8	16.4	78.3	17.6	2.3	10.0	08.0	01	12.9	07.1	04.7
26.	2-8 Apr.	14	39.1	20.1	62.3	18.4	3.0	09.1	00.0	00	13.6	09.1	06.5
27.	9-15 Apr.	15	38.9	19.6	56.3	12.3	3.8	10.2	00.0	00	12.2	06.5	07.7
28.	16-22 Apr.	16	41.1	21.9	48.2	12.4	5.0	10.5	00.0	00	11.7	07.1	08.8
29.	23-29 Apr.	17	40.2	20.9	46.0	11.0	5.1	10.4	00.0	00	11.6	06.2	09.4
30	30-6 May	18	41.5	22.7	38.0	14.0	6.9	09.8	03.2	01	10.9	07.8	10.7

Appendix II. Mean value of thirty genotypes of wheat

Genotype	Date of 50% heading	Days to maturity	Plant height	Peduncle length	Ear length	Ear weight	No. of effective tillers	No. ears/plant	No. of spikelet/spike	No. of grains/ear	Grain yield/plant	1000 grain wt	Biological yield	Harvest Index	Chlorophyll Content	Canopy Temp.	Relative water content
PYT-2	72.67	117.00	95.93	14.17	9.53	2.03	5.53	5.33	13.30	32.63	6.22	35.34	27.70	22.44	45.93	19.07	78.52
PYT-6	73.33	119.67	99.20	16.27	10.83	2.97	5.93	5.80	14.63	36.97	8.57	38.67	36.51	23.49	44.60	20.43	73.62
PYT-16 ©	78.33	124.67	102.93	18.63	12.10	3.63	6.20	6.00	15.47	44.40	10.01	40.56	25.37	39.44	40.13	19.60	72.29
PYT-21	72.67	117.33	97.47	14.87	9.57	2.19	6.40	6.40	13.23	33.87	6.91	39.12	32.26	21.41	37.60	21.30	78.60
PYT-22	80.00	123.00	102.33	20.40	12.37	4.00	5.67	5.50	15.27	42.67	10.34	42.62	28.30	36.55	40.10	20.57	77.22
PYT-23	80.00	121.67	98.97	13.50	9.43	1.93	7.23	7.10	13.50	35.87	7.16	39.20	27.27	26.27	42.41	18.23	80.28
PYT-24	77.67	118.67	92.87	13.40	9.73	2.20	6.43	6.33	13.50	38.87	5.80	37.38	20.36	28.51	43.88	19.33	78.90
PYT-25	78.00	118.33	98.67	14.93	9.60	2.00	4.47	4.37	13.30	37.37	6.58	35.31	22.47	29.28	43.86	22.43	68.26
PYT-27	82.00	122.00	100.20	17.60	11.60	3.40	4.63	4.57	14.43	44.70	9.44	42.52	20.43	46.21	45.75	18.80	79.77
PYT-40	71.67	119.00	103.67	19.67	12.83	4.10	7.13	7.03	17.50	52.93	10.69	44.66	42.07	25.40	39.13	20.17	68.73
PYT-46	75.33	122.33	99.32	18.70	12.13	3.70	4.53	4.50	14.93	42.47	7.75	38.23	35.19	22.01	37.59	19.33	79.75
PYT-47	79.33	124.00	95.67	14.80	10.00	2.83	6.77	6.67	13.67	40.33	8.77	35.46	40.07	21.88	46.36	18.07	72.54
PYT-49	82.67	126.67	108.60	20.90	13.10	4.27	6.30	6.07	16.47	48.00	9.32	41.37	46.82	19.89	44.46	23.10	69.64
PYT-51 ©	76.67	122.00	95.93	16.60	10.30	2.67	7.67	7.60	16.40	47.57	9.69	42.58	42.07	23.04	40.00	22.53	78.64
PYT-57	76.00	122.00	93.77	11.87	9.17	1.97	6.17	6.03	12.73	48.87	11.58	45.66	45.00	25.72	45.60	18.53	74.69
PYT-58	74.00	120.33	93.93	12.50	9.53	1.87	7.40	7.37	13.27	37.50	8.07	36.87	36.57	22.07	38.61	18.67	72.35
PYT-60	76.66	124.00	96.63	15.60	11.83	3.40	5.37	5.30	17.40	51.57	11.55	45.80	29.83	38.71	45.35	20.67	78.20
PYT-61	74.66	122.00	98.90	15.73	12.00	3.47	7.80	7.77	14.93	52.23	10.61	43.21	30.40	34.91	39.78	21.90	79.57
PYT-66	78.66	125.33	98.47	17.60	12.23	3.73	6.37	6.30	14.80	39.63	8.57	38.30	34.33	24.97	42.42	19.30	79.00
PYT-68	77.33	125.33	92.17	14.70	9.70	2.30	6.00	5.97	15.27	48.87	10.54	44.14	41.97	25.12	40.79	18.33	72.73
PYT-69	80.00	126.33	87.43	11.93	9.00	1.80	6.40	6.40	16.43	52.70	11.01	46.05	38.33	28.73	37.81	21.47	67.51
PYT-89	76.00	123.33	91.70	15.53	11.83	3.33	7.33	7.27	15.23	49.80	7.27	35.92	29.87	24.33	39.46	20.47	73.35
PYT-97	73.33	121.33	95.13	18.10	11.93	3.37	7.60	7.57	16.67	50.67	9.97	39.73	40.27	24.75	41.57	22.60	78.50
PYT-101 ©	79.00	123.00	95.83	14.80	10.20	2.60	8.70	8.67	14.10	40.67	9.87	40.42	36.34	27.15	43.66	17.73	68.87
PYT-104	78.66	127.33	99.40	19.43	11.77	3.23	5.27	5.20	17.23	52.87	11.20	41.40	44.24	25.31	40.57	19.77	72.60
PYT-109	71.00	117.00	92.17	15.93	10.47	2.37	5.00	4.93	13.37	45.60	9.89	40.79	35.93	27.52	38.49	20.07	74.64
PYT-115	80.67	127.67	99.13	17.60	10.47	2.60	7.77	7.73	14.63	49.10	10.49	40.79	44.23	23.71	44.18	18.50	69.59
PYT-118	76.67	123.67	100.60	18.93	12.20	3.57	6.23	6.17	16.27	52.80	10.86	41.73	39.90	27.21	46.31	22.53	79.26
PYT-120	77.00	125.67	98.60	17.13	10.67	3.00	4.53	4.53	14.77	43.03	9.32	42.48	38.37	24.29	43.21	21.53	76.38
PYT-122	69.67	116.33	105.53	21.00	12.03	3.67	6.00	5.87	15.73	47.67	9.93	41.83	40.93	24.26	42.54	20.40	75.17

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