GENETIC EVALUATION OF GENOTYPES IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA FOR DROUGHT TOLERANCE IN WHEAT (*Triticum aestivum* L.)

Thesis Submitted for the Award of the Degree of

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in

Botany

By

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Transforming Education Transforming India

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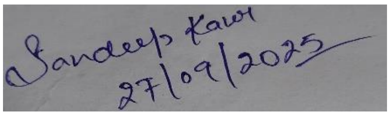
DECLARATION

I hereby declared that the presented work in the thesis entitled **"GENETIC EVALUATION OF GENOTYPES IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA FOR DROUGHT TOLERANCE IN WHEAT (*Triticum aestivum* L.)"** in fulfilment of degree of **Doctor of Philosophy (Ph. D.) Botany** is outcome of research work carried out by me under the supervision of **Dr. Anupam Kumar**, working as **Associate Professor**, in the **Department of Biotechnology, School of Bioengineering and Biosciences** of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgments have been made whenever the work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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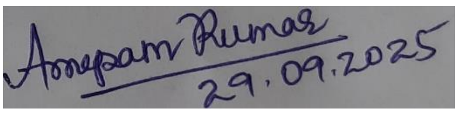
CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled "GENETIC EVALUATION OF GENOTYPES IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA FOR DROUGHT TOLERANCE IN WHEAT (*Triticum aestivum* L.)" submitted in fulfillment of the requirement for the award of the degree of **Doctor of Philosophy (Ph.D.)** in the **Department of Botany**, School of Bioengineering and Biosciences, is a research work carried out by **Sandeep Kaur**, **Registration No.11512765**, is a bonafide record of his/her original work carried out under my supervision and that no part of the thesis has been submitted for any other degree, diploma or equivalent course.



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Abstract

The Present study entitled "GENETIC EVALUATION OF GENOTYPES IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA FOR DROUGHT TOLERANCE IN WHEAT (*Triticum aestivum* L.)" was carried out to examine the component of variance, combining ability, heterosis, inbreeding depression, heritability and genetic advancement in under drought stress conditions. The experimental material comprised 10 parents, and their 45 cross combinations produced through the half-diallel crossing method (without reciprocals) in *Rabi* 2017-18, 2018-19, and 2019-20 at agriculture research farms, Lovely Professional University Phagwara Punjab and Meerut, Uttar Pradesh. The experiment was laid out in a Randomized complete block design with three replications. The data was recorded for eleven characters.

The analysis of variance for all the attributes revealed that the mean squares due to genotypes were highly significant for all the characters studied in both locations. The analysis of variance also depicted significant differences for all the characters in treatments, parents, hybrids, and parents vs. hybrids in both Punjab and Uttar Pradesh trials under drought stress conditions. The significant mean sum of squares differences for the attributes evaluated among parents demonstrated that the material used in this study had adequate variability for diverse attributes.

The estimates of $\sigma 2A$ were positive in magnitude for all of the traits. The magnitude of $\sigma 2D$ was higher than $\sigma 2A$ for all the traits in Punjab and Meerut, U.P. except for Days to 75% flowering in both and No. of spikelets/spike in U.P. where $\sigma 2A$ was higher than $\sigma 2D$. Traits like days to 75% flowering, plant height, 1000-seeds weight, spike length, harvesting index, and biological yield showed the high narrow-sense heritability estimates (>30%) in both Punjab as well as Meerut, Uttar Pradesh trials.

The analysis of variance for combining ability revealed significant gca differences for all traits and significant sca differences for the majority of traits, except for the number of grains per spike in Meerut Uttar Pradesh. The ANOVA revealed the impact of both additive and dominant gene activities in the expression of different phenotypes. For every character under study, the GCA / SCA variance ratio was less than unity, indicating the significance of non-additive gene activity.

Parent IC138866, IC532889, IC82322, and IC55681 were identified as ideal general combiners for various attributes based on assessments of their general combining ability.

Specific combining ability showed the crosses IC82322×IC78751, IC212140×IC78751, IC82322×IC75310, IC138866×IC78837 in both Punjab and Meerut trials, appeared most favorable for grain yield per plant including some related traits. With further wheat breeding efforts, these crosses have a strong chance of increasing grain output.

Based on the top three heterosis and heterobeltiosis cross performers, IC212140×IC78737, IC55681×IC78837, and IC82322×IC78751 showed promising significant results for grain yield per plant and other traits whereas, IC138866×IC78837 showed promising results for different attributes. Most of the traits showed desirable inbreeding depression for most of the traits. For the grain yield per plant crosses, IC82322×IC78551 showed the desirable inbreeding depression in both trials whereas, IC138866×IC78837, IC 212140×IC78737, IC55681×IC78837 exhibited the desirable outcome.

Plant height, 1000-sseds weight, grain production per plant, number of tillers per plant, and harvesting index were the most heritable traits, with a strong genetic advance as a percentage of the mean.

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Sandeep Kaur

Table of Contents

List of Table

List of Figures

Chapter 1

1. Introduction

Wheat plays a vital role in global agriculture and is one of the most dominant food crop in many regions of the world. Studies suggest that over 35% of the global population relies on wheat for sustenance, as it provides essential nutrients, including vital amino acids, surpassing other single crops in its nutritional value. For a sizable section of the population in India, especially in the north and centre, wheat is a staple diet. India is one of the world's largest producers of wheat, consistently ranking among the top producers alongside countries like China, the United States, and Russia. The production and export of wheat contribute to India's position in global agricultural markets. In Indian agriculture, wheat plays a crucial role in ensuring food security, alleviating poverty, and ensuring the livelihoods of millions of farmers and labourers. Wheat plays a crucial role in crop rotation systems, alternating with other crops like rice, pulses, and oilseeds. This rotation helps improve soil fertility, reduce pest and disease pressure, and enhance overall agricultural sustainability. After rice, it is India's second most important food crop, both in terms of area under cultivation and production. The huge area under cultivation, the high productivity, and the strong presence in the international grain trade underline the importance of the plant, which is known as the "king of grains". However, the country's productivity is in thirteenth place, slightly below the global average. Nevertheless, the country has seen a positive trend in overall production with an annual growth rate of 2.57%. While acreage expansion plays an important role in this historic production, the remarkable yield increases in the traditional wheat-growing states like Punjab, Haryana, and Madhya Pradesh are an encouraging sign for the national grain reserves.

Wheat, scientifically known as *Triticum aestivum* L., is a versatile cereal grain often referred to as the cornerstone of sustenance. Its significance extends deeply into human culture, with a history intertwined with the development of civilization itself. Even in modern times, wheat maintains its paramount position among cereal crops, serving as a vital source of sustenance for humanity.

1.1 SCIENTIFIC CLASSIFICATION

Kingdom	Plantae
Sub kingdom	Tracheobionta
Superdivision	Spermatophyte

Division	Magnoliophyta
Class	Liliopsida
Subclass	Commelinidae
Order	Cyperales
Family	Poaceae
Genus	*Triticum*
Species	*Triticum aestivum*

Wheat is quite adaptable to a variety of agro-climatic conditions throughout India, from the plains of Punjab and Haryana to the semi-arid zones of Rajasthan and Gujrat. Its adaptability to varied settings makes it a versatile and durable crop. Given its cultivation across diverse climatic conditions, understanding wheat genetics is important for genetic research and plant breeding efforts The nutrient-dense crop covers 220.83 million hectares worldwide, with production reaching a record high of 769.31 million tons, according to USDA data. Wheat cultivation spanned 30.55 million hectares in India during the 2019-20 Rabi season, representing 24.94% of total agricultural land use. This time marks a watershed moment in Indian agriculture, with wheat production reaching 107.18 million tons and yielding an average of 3508 kg per hectare.

1.2 Impact of drought on food security and wheat

Drought poses a significant threat to global food security, including wheat production. Wheat is a water-intensive crop and drought can severely affect its growth, development and yield. Drought-related yield losses can have devastating consequences for farmers, especially smallholder wheat growers. Lower yields lead to lower incomes, higher indebtedness and increased vulnerability to poverty and food insecurity. This difficulty is particularly acute in arid semi-arid countries, where rainfall patterns shift year to year. For example, exceptionally low rainfall in 1979 reduced India's entire food grain production by 20%. The 1987 drought ruined 58.6 million hectares of cropland, affecting more than 285 million people. Since 2001, the country has seen three major droughts.

Coping with drought is therefore crucial to ensure the economic well-being of farming communities. Climate change is exacerbating the frequency, intensity, and duration of drought events in many regions, including those where wheat is grown. Rising temperatures, changing precipitation patterns and increased evapotranspiration contribute to greater water stress in agricultural ecosystems and increase the vulnerability of crops such as wheat to drought. Traditional drought management strategies may no longer be sufficient in the face of more frequent and severe drought events. Innovative approaches, including the development of drought-tolerant crop varieties, improved water management practices, and resilient cropping systems, are needed to increase adaptive capacity and improve agricultural sustainability. Drought-related interruptions in wheat production due to drought in major producing regions can have far-reaching implications for food availability, accessibility, and affordability, particularly for countries that rely heavily on wheat imports. A substantial decrease in food grain production from 212 million tons the year before to 174 million tons as a result of the 2002 drought led to a 3.2% decline in the agriculture sector's GDP contribution (Rathore et al., 2014). Despite employing more than half of India's workforce, agriculture's share of the national GDP has steadily declined from 51.9% in 1950-51 to 13.7% in 2012-13. To make matters worse, around 56% of India's agricultural land is dependent on rainfall, rendering it susceptible to irregular weather patterns (GoI, 2013). Research on drought patterns and their impact in India revealed variable frequency of drought conditions in different regions (Mishra et al., 2014; Thomas et al. 2015). Furthermore, Zhang et al. (2017) found that drought intensity and frequency increased from 1901 to 2004 in India. As a result, prioritizing the development and adoption of drought-resistant crop varieties is critical for reducing the negative effects of droughts and stabilizing crop output (Dorostkar et al., 2016). Thus, Addressing drought stress in wheat production is imperative for ensuring food security, safeguarding farmers' livelihoods, mitigating economic losses, and enhancing resilience in climate change-induced challenges. Efforts to develop and deploy drought-tolerant crop varieties and sustainable agricultural practices are essential components of a comprehensive strategy to adapt to changing environmental conditions and sustainably meet the growing demand for food.

1.3 Role of Agro-climatic zones in agriculture research and crop breeding

Agro-climatic zones are areas characterized by specific combinations of temperature and moisture regimes. These zones have a significant impact on agricultural research and crop breeding as they provide important information about the suitability of different crops and their potential productivity in specific regions. India has a diversified set of agro-climatic variables, including temperature regimes, rainfall patterns, different soil types, and altitude disparities. Wheat genotypes that thrive well in one place may not thrive in another due to environmental changes. India has a high genetic diversity of wheat, with multiple landraces and wild relatives adapted to different agro-climatic conditions. Evaluating wheat genotypes across different zones enables researchers to investigate and utilize genetic variability for crop improvement. Identifying innovative genetic resources with desirable features, such as high yield potential, abiotic and biotic stress tolerance, and nutritional quality, can help improve wheat types through breeding operations. By examining wheat genotypes in various contexts, researchers can help to generate improved varieties that fit the changing demands of farmers and consumers, ultimately improving food security and livelihoods.

In wheat breeding, programs focused on enhancing yield and yield-contributing traits, the utilization of both native and foreign germplasm is vital for success. Natural plant populations inherently possess significant variability in adaptation across different environments and over time. This variability is crucial, as it provides a diverse array of plants, increasing the likelihood of successful hybridization and the emergence of beneficial traits during genetic improvement processes.

Breeders are interested in knowing how much of a crop's variance is genetic and how heritable it is, in addition to gene effects. This is because additive genetic variance, environmental effect, and genotype-environment interaction are the key factors that determine selection efficiency. A thorough understanding of the gene activity governing the trait can be obtained using generation mean analysis (Hayman, 1954). To identify the main genetic influences influencing character variation, a first-degree statistical analysis technique is comparatively easy.

Selection and hybridization techniques play pivotal roles in refining the genetic makeup of a genotype. Selection involves the deliberate choice of plants with desirable traits to consolidate favorable genes, while hybridization is primarily employed to consolidate favorable genes from different sources into a single genotype, thereby enhancing overall performance. To achieve this, potential donor plants are identified from the available germplasm, which serves as a valuable natural repository of desirable attributes. Identifying suitable donor parents for key traits entails a thorough assessment of genetic variation within the existing germplasm pool, a critical step in devising effective breeding strategies to enhance wheat varieties.

The present investigations was planned with the following objectives:

1. To identify the trait(s) to form the basis of selection under moisture-stress conditions.
2. Genetic components of variance and their combining abilities including effects in F_1 generation.
3. Heterosis in F_1 and inbreeding depression in F_2 generation.
4. Heritability and genetic advancement in both generations especially of the character.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Components of Genetic Variance and Combining Ability

Shull (1909), Jones (1917), and East (1936) found that some lines create better hybrids than others in conventional heterosis investigations. Sprague and Tatum (1942) explained combining ability precisely. A genotype's ability to pass on its superior features or performance to its crossings is called combining ability. Handerson (1952) defined general combining ability as “the average value concerning a specific character or a weighted combination of characters derived from an infinitely large number of progenies of a line when crossed with a random sample from particular populations within a defined environment.” He defined specific combining ability as “a deviation of the mean value of a cross from the expected value determined based on the known general combining ability of the two parents or lines involved.” Griffing (1956) introduced the method of genetic correlation analysis utilising a diallel crossing system. The estimates of general combining ability encompass additive-based higher order epistatic variance, while the estimates of specific combining ability incorporate dominance and additional components of epistatic variance (Kempthorne, 1961). Comparable findings were also reported by Griffing in 1956. In the absence of epistasis, a diallel cross serves as a method for estimating both additive and dominance genetic variance.

Ahmad et al. (2007) identified a substantial additive and dominant gene influence on plant height, ear length, and grain yield under typical sowing settings. A substantial additive and predominant variation was identified for late sowing.

Kumar et al. (2008) determined that tiller count per plant, spikelet count per spike, grain count per spike, 1000-grain weight, and biological yield serve as robust selection markers for identifying high-yielding genotypes.

Bao-Yin Guang (2009) demontrated that additive gene action predominantly influences the regulation of characteristics such as SPL, FLA, and NSP. The findings indicated that parent SN 0095 was the superior general combiner for SL and FLA, and also a competent general combiner for the NSP among all parents. The evaluations of SCA revealed that the cross

SN0095 x Jimai 19 (NM 19) had the most significant SCA effect for grain yield. SN 0095 may serve as a distinctive and significant progenitor in the hybrid wheat breeding effort.

Muhammad et al. (2011) indicated that grain yield has a positive and substantial association with ear length, number of spikelets, 1000-kernels weight, and grain yield.

Yucel et al. (2011) indicated that the variations for combining ability demonstrated the involvement of both additive and non-additive gene influences in the regulation of most attributes. The magnitude of GCA exceeded that of SCA for all traits, with the exceptions of grain weight and plant height.

Burungale et al. (2011) documented both additive and non-additive gene activities significantly influenced the inheritance of characteristics. The ratio of genetic variances for General Combining Ability (GCA) and Specific Combining Ability (SCA) across all traits demonstrated that the majority of features were expressed as a result of non-additive gene activity such as plant height, no. of production tillers, length of the spike, number of spikelets per spike, number of grains/spike, 1000-seed weight, and grain yield/plant.

The research identified notable variations in genotypes concerning grains/spike, RWC, thousand-grain weight, and grain production/plant under both typical and arid circumstances. Lines 9438, 9444, and 9428 exhibited superior general combining ability, indicating their potential utility in forthcoming breeding operations **(Ashfaq et al., 2016).**

Khan et al. (2016) examined the performance of various bread wheat cultivars regarding yield and yield characteristics through diallel combinations. The current study showed that parents exhibited substantial variations in PH, grains/spike, grain weight/spike, 100-grain weight, and grain yield, although the dissimilarities in days to ear emergence and days to maturity were substantial, and biological yield dissimilarities were non-significant.

El-Said (2018) demonstrated significant differences in genotypes, parental lines, and crosses for all variables, except general combining ability. The study suggested enhanced non-additive gene interactions to improve performance. Hybrids IC212140xIC532889, IC82322xIC138866, and IC138866xIC78737 showed high grain yield per plant, with IC78737 and 1C78801 being the most effective general combiners. The study also found significant heritability in broad-sense variables and marked disparities in additive and dominant effects.

Taneva et al. (2019) observed considerable variance among genotypes for all examined variables, with the PCV) typically exceeding the GCV, suggesting the impact of the growing season. The maximum PCV was seen for sedimentation value, grain yield, and yellow color in grain, whereas the minimum PCV was recorded for test weight and protein content. Significant heritability was observed for yellow color in grain, thousand kernel weight, protein content, and vitreousness, suggesting successful selection.

2.2 Heterosis

Singh *et al*. (2007) observed heterotic response over economic parent based on combining ability for yield and quality attributes is eleven parents.

Singh *et al*. (2008) demonstrated that grain yield heterosis resulted from heterosis exhibited by the number of grains per spike, spike length, and test weight. The cross K9533 x K9423 was found top hybrid having high economic heterosis. Two crosses exhibited low inbreeding depression indicating additive x additive type of gene action.

Singh et al. (2009) investigated heterosis comparative to mid-parent value in 28 F1 hybrids concerning grain yield and seven allied features. The hybrid combination HVW468 x UIC532889425 exhibited superior heterosis for grain yield per plant.

According to **Bao-Yin Guang et al. (2009**), with the exception of KPS, TKW, and GYP, all of the crosses carried out by SN 0095 showed heterosis estimates for SL, No. of spikes/plant, no. of spikelets/spike, 1000-kernel weight, and grain yield/plant. Of all the qualities measured, the relative mid-parent heterosis (RMH) reached 35.32 percent and the relative better parent heterosis (RBH) 29.92 percent.

According to **Mohamad et al. (2014)** Genetics variation observed for key variables in wheat under both normal and drought settings. High heterosis noted for most studied characters, indicating potential for hybrid vigor. Over dominance found in the inheritance of all studied characters under both conditions. Genetic analysis showed over dominance in the inheritance of all examined traits across two crossings.

Said (2014) found that the Genetic variation was observed in spikes/plant, 100-seed weight, grain yield, biological yield, and chlorophyll content under normal and drought-stress environments in two crosses. High heterosis was observed, and dominant inheritance was found under both water treatments, except chlorophyll content The study found high genetic advance in grain yield (N&D) crosses, while biological yield, and chlorophyll content (N&D) showed moderate progress, emphasizing the importance of direct selection for these characters.

The research revealed that heterosis and inbreeding depression correlated with the direction and extent of most traits in three crossings under both conditions. Analysis of generation effects indicated additive, dominant, and epistatic influences on yield inheritance. Most traits exhibited high heritability estimates, with the exception of main spike yield in the initial cross under stress conditions. Moderate to strong genetic advancement was observed for all traits, indicating the feasibility of early generation selection **(Elmassry et al., 2018).**

Sharshar et.al. (2020) found significant heterotic effects and non-allelic interactions in the second and third crosses of grain yield under the typical and arid approaches. The effects of dominance were more pronounced than those of additive genes and heritability was high in a broad sense and moderate to high in the narrow sense. The third cross (Misr2 Line 3) exhibited the highest tolerance to water stress, making it recommended for use under water stress conditions.

2.3 Heritability and Genetic Advance

Heritability estimations indicate the degree of transmissibility of quantitatively significant characteristics that provide an effective approach to breeding crops. Heritability helps in projecting how future generations will act by assessing the level of genetic improvement and developing suitable picking criteria. Genetic advancement provides a comprehensive and precise understanding of segregating generations for potential selection. Elevated heritability estimates with improved genetic advancement, validate the potential for selection in creating novel genotypes with favorable traits.

Ahmad et al. (2007) reported narrow sense heritability estimates for flag leaf area and plant height, indicating potential for enhancement via initial generational screening. Conversely, narrow sense heritability estimates for spike length, grain yield per plant, and harvest index favored selection at a subsequent phase.

Bandyopadhyay et al. (2008) found the low heritability and gains from selection under adverse environments posed challenges in identifying suitable genotypes for high grain yield.

Two specific genotypes, SKW 196 and VL 738, performed effectively in typical and arid conditions, making them preferred choices for cultivation.

According to **Dagustu (2009),** there is a strong genetic component to plant height, number of tillers per plant, and gracious yield per plant. Plant height, grains per spike, days of 75% flowering, 1000-grain weight, and grain yield per plant also show a high level of heritability.

Ajmal et al. (2009) revealed that the broad sense heritability for plant height, tillers per plant, grains per spike, and grain yield exhibited high values while the heritability for the number of spikelets per spike was comparatively low. The relatively elevated estimates of heritability and genetic gain for plant height, tiller count, and grain yield per spike indicate that selection for these traits may be implemented with greater efficacy.

Eid M.H. (2009) demonstrated that spike length and 1000 grain weight exhibited significant heritability and substantial genetic progress. Plant height and the number of grains per spike exhibited limited genetic advancement and low heredity.

Bhushan et al. (2013) noted the maximum heritability estimate was recorded for all variables, and adequate genetic advance was noted for both the number of tillers per plant and the number of grains per spike.

Kumar et al. (2014) examined that significant genetic advancement was noted for plant height and biological yield per plant, whereas modest estimations were recorded for harvest index, and test weight, and minimal genetic advancement was seen for days to 50% blooming, spike length, and flag leaf length. Traits such as plant height, 1000 seed weight, and harvest index shown elevated heritability alongside significant genetic improvement.

Zerga et al. (2016) examined elevated heritability estimates for spikelets per spike, 1000 kernel weight, and plant height in a specific site. Significant genetic advancement was achieved in aboveground biomass (22.83%) and tillers per plant (21.61%) across several locales.

Kumar et al. (2017) assessed that the highest yield per plant was recorded for DBW 14 x K0424, followed by K 9162 x K 9423. Cross K 0607 x K 0911 demonstrated the highest protein content in the grain. High heritability was noted for protein content, whereas grain output per plant exhibited significant genetic advancement.

Climate change-induced drought reduces world wheat output and availability, with minimal progress in drought tolerance improvement. Grain yield and quality under water-limited circumstances can be improved by addressing prevailing pressures simultaneously in future research. (Mwadzingeni et al., 2016).

The study investigates the genetic diversity of stem traits in wheat and their significance in supporting grain weight under various conditions. Field experiments showed that stem diameter significantly correlates with thousand kernel weight, and grain yield per spike across the environments. High heritability estimates were found for SD in both generations. The study concludes that stem characters, particularly SD, may be crucial for sustaining grain filling under stressed conditions (**Ahmed Sallam et al., 2015).**

Naeem et al. (2015) indicated increased genetic variance for cell membrane stability, excised leaf water loss, relative water content, proline, sugar, and glycine betaine, implying their potential as direct selection criteria for wheat enhancement. Water loss from excised leaves and new root weight exhibited minimal variability, indicating indirect selection.

Mwadazingeni et al. (2017) identified substantial influences of genotypes, seasons, locations, and water regimes on wheat characteristics, with elevated heritability estimates for spike length, spikelet count per spike, plant height, kernels per spike, days to heading, and thousand seed weight. Moderate genotypic variation was seen for days to maturity, grain yield, and productive tillers per plant.

Table 2.3.1 Combining ability, Heterosis, and Genetic estimates in Wheat under Drought conditions

Authors/Year	Traits used for the study	Main findings or conclusion
Elmassry et al. (2018)	Number of spikes per plant, plant height, main spike length, no. of spikelets per main spike, no. of kernels per main spike, main spike yield, grain yield per plant, and 1000-kernel weight	The research revealed that heterosis and inbreeding depression correlated with the direction and extent of most traits in three crossings under both conditions. Most traits exhibited high heritability estimates, except for the main spike yield in the initial cross under stress conditions. Moderate to strong genetic advancement was observed for all traits, indicating the feasibility of early-generation selection.

El-Said (2018)	Days to heading, days to maturity, plant height, number of spikes /plant, spike length, number of spikelets /spike, number of kernels /spike, 1000-kernel weight, and grain yield /plant.	Significant differences were found in genotypes, parental lines, and crosses for all variables, except general combining ability. The study suggested enhanced non-additive gene interactions to improve performance. Hybrids P1xP2, P3xP5, and P5xP6 showed high grain yield per plant, with P6 and P8 being the most effective general combiners. The study also found significant heritability in broad-sense variables and marked disparities in additive and dominant effects.
Kaur et al. (2019)	Days to 50% heading, days to maturity, plant height, number of productive tillers per plant, number of spikelets per ear, ear length, ear weight, number of ears per plant, number of grains per ear, 1000-grain weight, biological yield per plant, grain yield per plant, harvest index.	Significant variations were observed among genotypes in several traits, including grain yield, ear count per plant, productive tiller count per plant, harvest index, and grain yield. Notable genetic diversity was identified in these traits, along with high heritability in the number of ears per plant, plant height, and ear weight.
Sharshar et.al. (2020)	Days to heading, days to maturity, plant height, number of spikes per plant, number of grains per spike, 100-grain weight, and grain yield per plant.	Significant heterotic effects and non-allelic interactions were observed in the second and third crosses of grain yield under the typical and arid approaches. The effects of dominance were more pronounced than those of additive genes, and heritability was high in a broad sense and moderate to high in the narrow sense. The third cross (Misr2 Line 3) exhibited the highest tolerance to water stress.

Gerema et al. (2020)	Plant height, productive tillers per plant, number of kernels per spike, number of spikelets per spike, and spike length.	A study assessing 180 genotypes demonstrated substantial heterogeneity in characteristics. Heritability and genetic progress were greater for kernels per spike and the grain filling duration. Grain yield unveiled a positive correlation with tillers, kernels per spike, and plant height.
Basiya et. al. (2020)	Days to heading, days to maturity, grain filling period, plant height, number of productive tillers, number of spikelets per spike, spike length, number of kernels per spike, biomass yield, grain yield at 12.5% moisture, harvest index (%), and thousand kernel weight.	Location effects were noteworthy for yield and yield-related traits, except for the harvesting index. Heritability estimates were high, apart from grain yield and kernel per spike. Nevertheless, low GAM was observed for the harvest index. Selection and hybridization could improve bread wheat yield.
Elmassary et al. (2020)	Number of days to heading, number of days to maturity, plant height, number of spikes per plant, 1000-kernel weight, number of kernels per spike, grain yield per plant, flag leaf area.	Significant or highly significant variations were found among wheat genotypes and their crosses for most traits under normal and water-stress conditions. General and specific combining abilities were significant for most traits, indicating their importance in breeding drought-tolerant wheat.
Samahegn et al. (2021)	Days to heading, days to maturity, spike length, plant height, spikelets/spike, kernel per spike, 1000 kernel weight and grain yield.	Considerable genetic diversity in agronomic characteristics was found under both drought-stressed and non-stressed environments. The significant heritability and direct selection for DH, SL, and SS indicate their efficacy. GY exhibited minimal genetic progress and intricate inheritance patterns. TKW was the primary characteristic for enhancing grain yield.

Haleem et.al. (2022)	Plant height, No. of tillers, spike length, spikelets per spike, 1000-grain weight and grain yield.	Significant genetic variation was found among lines, parents, F2 progenies, and parent versus F2 progenies for various traits. The best lines were Atta-Habib for plant height, Janbaz for economic yield per plant, and Khatakwal for 100-grain weight. F2 progenies were the best combinations for plant height, economic yield per plant, and spikelets per spike. High broad-sense heritability was recorded in cross combinations, and F2 progenies were found promising for future wheat breeding programs.
Panhwar et al. (2022)	Days to 50% flowering, days to 90% maturity, plant height, main spike length, tillers plant- ^{1}, spikelet spike- ^{1}, grains spike- ^{1}, 1000 grain weight, grain yield plant- ^{1}, biological yield- ^{1}, harvest index, flag leaf area, leaf relative water content, and chlorophyll content.	F1 wheat hybrids were evaluated for heterosis under water stress conditions, identified specific hybrids with potential for seed yield under different watering conditions, and suggested strategies to improve hybrid performance in wheat breeding. The F1 hybrids Sarsabz × Kiran-95 (V7), TD-1 × NIA Sarang (V8), and NIA Sarang × Kiran-95 (V10) were found to be significant hybrids for kernel yield under both typical and arid conditions.

Hamid et al. (2017) identified considerable variations across wheat genotypes in all examined traits, with the exception of chlorophyll content and spikes per square metre. Line 3, Sids 12 Misr 1, and Line 4 had strong performance in terms of yield and its components despite late planting dates. Spike length, the number of viable spikelets per spike, the number of spikes per square metre, the number of grains per spike, and the weight of 1000 grains were the most significant variables associated with grain yield at both genotypic and phenotypic levels. An modest enhancement in one of these characteristics may directly influence grain yield, rendering them valuable selection criteria for boosting wheat grain output.

Kaur et al. (2019) identified significant variations among genotypes in several traits, including grain yield, ear count per plant, productive tiller count per plant, harvest index, and grain yield. Significant genetic diversity was noted in these characteristics, accompanied by elevated heritability in the number of ears per plant, plant height, and ear weight.

Understanding variance compoments and heritability is crucial for breeding strategies. Drought stress reduces heritability of RS and GY. Direct selection for DTH, PH, RB, and TKW could help optimize root-shoot ratio and increase resilience to drought and crop production in drought-stricken areas **(Mathew et al., 2018).**

Al-Salimiyia et al. (2018) screened six wheat genotypes in West Bank, Palestine, for drought-tolerant traits using phenotypic markers. The Yellow-Hetia genotype showed the highest growth indicators and yield, while the Nab-El-Jamal and Um-ElRabee genotypes had similar production. Yellow-Hetia presents a potential cultivar of interest for upcoming breeding initiatives, especially for drought tolerance.

Tadesse et.al. (2019) found that hybrid wheat has significant potential for increased productivity due to higher yields, deeper roots, and better stress resistance. Nonetheless, obstacles encompass an absence of well-defined heterotic groups and elevated expenses associated with seed production. Utilizing new molecular tools, strengthening international networks, and promoting partnerships among institutions can help develop sustainable wheat technologies.

Alemu et al. (2020) identified substantial variances across accessions for all characteristics, likely attributable to genetic differences. The elevated heritability and genetic advance values for plant height indicate that trait enhancement by selection is more feasible. Genotypic and phenotypic coefficients varied from 3.08 to 18.93, exhibiting positive connections among grain yield, biological yield, thousand seed weight, and harvest index. The most significant genotypic direct impacts were attributed to days to maturity, biological yield, and harvest index. The initial five major components represented 81.58% of the overall variation. This variability can assist in the planning of selection and crossing programs for the enhancement of durum wheat.

Gerema et al. (2020) found in a study assessing 180 genotypes demonstrated substantial heterogeneity in characteristics. Heritability and genetic progress were greater for kernels per spike and the grain filling duration. Grain yield unveiled a positive correlation with tillers, kernels per spike, and plant height. The study's results may assist in breeding initiatives intended to improve favorable features in durum wheat.

Basiya et. al. (2020) revealed that a study of thirty wheat genotypes in Southeastern Ethiopia found significant differences in yield and related traits. Location effects were noteworthy for yield and yield-related traits, except for harvest index. Heritability estimates were high apart from grain yield and kernel per spike. Nevertheless, low GAM was observed for the harvest index. Selection and hybridization could improve bread wheat yield.

Samahegn et al. (2021) identified considerable genetic diversity in agronomic characteristics under both drought-stressed and non-stressed environments. The significant heritability and direct selection for DH, SL, and SS indicate their efficacy. GY exhibited minimal genetic progress and intricate inheritance patterns. TKW was the primary characteristic for enhancing grain yield.

Haleem et.al. (2022) found significant genetic variation among lines, parents, F2 progenies, and parent versus F2 progenies for various traits. The best lines were Atta-Habib for plant height, Janbaz for economic yield per plant, and Khatakwal for 100-grain weight. F2 progenies were best combinations for plant height, economic yield per plant, and spikelets spike. High broad sense heritability was recorded in cross combinations, and F2 progenies were found promising for future wheat breeding programs.

Panhwar et al. (2022) evaluated F1 wheat hybrids for heterosis under water stress conditions, identified specific hybrids with potential for seed yield under different watering conditions, and suggested strategies to improve hybrid performance in wheat breeding. The F1 hybrids Sarsabz × Kiran-95 (V7), TD-1× NIA- Sarang (V8), and NIA-Sarang × Kiran-95 (V10) were found probable wheat hybrids for kernel yield under typical and arid settings, which could be included in the future wheat breeding scheme.

Ahmad et al. (2022) found that genotypes Faisalabad-2008 exhibited a superior yield attributable to the increased number of tillers per plant and spikelets per spike. Identifying drought-tolerant genotypes could serve as a more effective strategy to mitigate the impacts of drought on wheat in areas susceptible to such conditions.

Chapter 3

Material and Methods

This chapter provides a comprehensive overview of the materials and methods used in the current study, which focuses "Genetic evaluation of genotypes in different Agro-climatic zones of India for Drought tolerance in Wheat (*Triticum aestivum* L.).

3.1 Experimental material:

The experimental materials for the research included 10 wheat genotypes and 45 F1 hybrids, along with AA forceps, scissors, crossing bags (butter paper bags), crossing tags, and a stapler. Absolute ethanol utilised for the sterilisation of forceps and scissors was procured from Himedia, India

3.2 List of genotypes

The ten genotypes that were used for crossing in the research endeavor are enlisted in Table 3.1. The crosses so generated are presented in Table 3.2. The 45 F1s so generated along with 10 parental genotypes were evaluated using Randomised complete block design(RCBD), the layout of which is presented in Table 3.4.

Table 3.1 Genotypes and Source

S. No.	Name of Genotype	Source	Pedigree
1	IC212140	NBPGR	Germplasm
2	IC532889	NBPGR	Germplasm
3	IC82322	NBPGR	Germplasm
4	IC78751	NBPGR	Germplasm
5	IC138866	NBPGR	Germplasm
6	IC78737	NBPGR	Germplasm
7	IC55681	NBPGR	Germplasm
8	IC78801	NBPGR	Germplasm
9	IC75310	NBPGR	Germplasm
10	IC78837	NBPGR	Germplasm

Table 3.2 List of crosses

S. No.	Crosses	S. No.	Crosses
1	IC 212140×IC532889	24	IC82322×IC78837
2	IC 212140×IC82322	25	IC78751×IC138866
3	IC 212140×IC78751	26	IC78751×IC78737
4	IC 212140×IC138866	27	IC78751×IC55681
5	IC 212140×IC78737	28	IC78751×1C78801
6	IC 212140×IC55681	29	IC78751×IC75310
7	IC 212140×IC78801	30	IC78751×IC78837
8	IC 212140×IC75310	31	IC138866×IC78737
9	IC 212140×IC78837	32	IC138866×IC55681
10	IC532889×IC82322	33	IC138866×1C78801
11	IC532889× IC78751	34	IC138866×IC75310
12	IC532889×IC138866	35	IC138866×IC78837
13	IC532889× IC78737	36	IC78737×IC55681
14	IC532889× IC55681	37	IC78737×1C78801
15	IC532889× IC78801	38	IC78737×IC75310
16	IC532889× IC75310	39	IC78737×IC78837
17	IC532889× IC78837	40	IC55681×1C78801
18	IC82322× IC78751	41	IC55681×IC75310
19	IC82322× IC138866	42	IC55681×IC78837
20	IC82322× IC78737	43	1C78801×IC75310
21	IC82322× IC55681	44	1C78801×IC78837
22	IC82322× IC78801	45	IC75310×IC78837
23	IC82322× IC75310		

3.3 Location of the experimental plot:

The experimental site was situated at the agriculture research farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab and Meerut, Uttar Pradesh.

3.4 Experimental Layout:

The layout of the crossing plan through half diallel mating design without reciprocals is given in Table 3.3.

3.4.1 Experiment 1: Ten diverse genotypes were selected and sown to generate 45 F1 progenies by crossing during the *Rabi* 2017-18 by employing a half-diallel mating approach. Three rows of five-meter length were prepared for each plot. The distance between rows was 25 cm, while the distance between plants was 10 cm. The spacing between plants was maintained at 10 cm by thinning of extra plants. Half-diallel mating approach (excluding reciprocals) was applied for the crossing of the parental genotypes.

Table 3.3: Layout of crosses (Half-diallel design without reciprocals) 10×10

1	**×**	**1×2**	**1×3**	**1×4**	**1×5**	**1×6**	**1×7**	**1×8**	**1×9**	**1×10**
2		×	2×3	2×4	2×5	2×6	2×7	2×8	2×9	2×10
3			×	3×4	3×5	3×6	3×7	3×8	3×9	3×10
4				×	4×5	4×6	4×7	4×8	4×9	4×10
5					×	5×6	5×7	5×8	5×9	5×10
6						×	6×7	6×8	6×9	6×10
7							×	7×8	7×9	7×10
8								×	8×9	8×10
9									×	9×10
10										×

3.4.2 Experiment 2: Forty-five F1 hybrids and ten parental lines were assessed using a half-diallel design with three replications during the Rabi season of 2018-19. Three rows of five-meter length were prepared for each plot. The inter-row and intra-plant spacing was maintained at 25 cm and 10 cm, respectively.

3.4.3 Date of sowing

a. During *Rabi* 2017-2018 the seeds were line sown on 24th Nov. 2017.

b. During *Rabi* 2018-2019 the seeds were line sown on 26th Oct. 2018 (Punjab) and 29 Oct.2018(Meerut).

c. During *Rabi* 2019-2020 the seeds were line sown on 18^{th} November 2019 (Punjab) and 22 November 2019 (Meerut).

3.4.4 Irrigation

Irrigation was conducted on the 60th and 90th days post-sowing to achieve drought conditions throughout the season.

3.4.5 Intercultural operations

Intercultural activities, like as thinning, were conducted just once over the entire crop cycle, three weeks post-sowing. Manual weeding was conducted consistently upon their emergence.

3.4.6 Harvesting

When the entries reached their physiological maturity, they were harvested.

3.5 Observations recorded:

Data for all attributes were collected from five randomly chosen plants in each replication. The observations from the five plants were averaged via replication, and the resulting mean data were analyzed statistically using Indostat software. The methodology employed for observing distinct traits is detailed below.

3.5.1 Days to Seventy percent flowering

The genotypes were meticulously monitored from the sowing date till the onset of flowering in 75% of the plants within each treatment replication, and the duration was documented.

3.5.2 Days to maturity

The duration from seed sowing to physiological maturity was documented for each entry in every replication.

3.5.3 Plant height (cm)

The height of the plant was recorded in centimeters, measured from the ground level to the apex of the primary mother axis at maturity.

3.5.4 Number of spikelets per spike

From each replication, five spikes of randomly chosen plants were counted to determine the number of spikelets per spike.

3.5.5 Number of grains per spike

The grains per spike were counted from five randomly selected spikes of five randomly chosen plants for each genotype in each replication, and the results were averaged.

3.5.6 1000 seed weight (g)

A total of 1000 seeds from the bulk stock of each test entry were collected and weighed at a moisture content of 5-6 percent, referred to as 'wet weight', following ISTA regulations. This process was conducted in triplicate, and the average weight of 1000 seeds was calculated in grams.

3.5.7 Grain yield per plant (g)

The total seeds recovered via hand threshing from the five randomly selected plants were weighed in grams to establish the average.

3.5.8 Spike length (cm)

A measurement was taken from the base of the spike to the tip of the spike in order to determine the length of the spike in centimeters.

3.5.9 Number of tillers per plant

The total number of tillers that emerged from the primary shoot was counted, and an average value was calculated.

3.5.10 Harvest index (%)

The ratio of economic yield to biological yield was documented as a percentage. The Harvest Index was determined using the formula established by Donald and Hamblin in 1976.

3.5.11 Biological yield per plant (g)

The biological yield of five randomly selected plants was measured in grams before threshing, and an average was calculated for each replication.

3.6 Statistical Analysis

The experimental data was gathered by calculating the mean of sampled plants across all three replications for each treatment.

3.6.1 Analysis of Genetic Components

Table 3.4 Equations of components of variance

Symbol	Formulae	Genetic parameters
D	$V_OL_O - E_2$	Additive variance
H1	V_OL_O-4W_OL_O1+4V_1L_1-E(3n-2/n)	Variation resulting from the dominant influence of genes
H2	4V1L1-4V_OL1-2E	Variation resulting from the dominant effect of a gene is associated with the distribution of that gene.
h^2	4(ML_1-ML_O)2-4(n-1)E/n2	Over all dominant effect of heterozygous loci
F	2V_OL_O-4W_OL_O1-2(n2)E/n	The ratio of the predominant allele to the recessive allele

E	{(ESS+RSS)/Edf+Rdf)}/nR	Environmental variance
$h2_{ns}$	½ D + ½ H1 -½H2 -½F / ½D +½ H1 – ¼ H3 -½F + E1	Narrow sense heritability

3.6.2 Analysis of variance for combining ability

The combining ability analysis was conducted following the methods proposed by Griffing (1956 a,b) Method- II, Model-1, which assumes that the effects of variety and block are constant (fixed).

$$Yijk = \mu + gi + gj + sij + [1/r]\sum eijk$$

Where

The value of Yijk is the hybrid performance in the kth cross-replication for each i, where i ranges from 1 to j.P (where i and j are the values of the parents' numbers) and k = 1, 2, 3,...The variables ν, gi, gj, sij, and eijk indicate many aspects of the data, including the overall average, the effects of the ith and jth parents on the offspring, and the environmental effect related to the ijkth observation. The integer k represents the number of replications.

This model is used to conduct the following analysis of variance for the combining ability.

Source	Df	S.S	M.S.S	E.M.S
gca	(p-1)	S_g	M_g	$\sigma 2e + (p+2)1/(p-1)\sigma ig2i$
Sca	P(p-1)/2	S_s	M_s	$\sigma 2e + 2/P(p-1)$
Error	(g-1)(r-1)	S_e	Me	

Where,

p equals the total number of parents, and G is the number of descendants. The general combining ability causes the sum of squares to be Sg. Ss = Total of squares resulting from skill in a given combination, Yi is the sum of all parenting arrays, Yii = Average of the ith parent's values, The sum of the parents' and half-diallel matrix's accounts is Y... Yij is the average value of the ijth cross. Me= The square of the error in the experimental design analysis Number of replications (R) Me was used to calculate variance ratio (F) as a test of *gca* and *sca* mean squares.

Genetic component of variance were estimated as under:

Variance due to *gca* (g i2) = (Mg – Me’) (p/p+2)

Variance due to *sca* (sij2) = (Ms – Me’)

3.6.3 Estimation of heterosis and inbreeding depression

Heterosis over mid-parent

Mid parent heterosis (%) = $\frac{F1-MP}{MP} \times 100$

Heterosis over better parent

Heterobeltiosis (%) = $\frac{F1-BP}{BP} \times 100$

Inbreeding depression

The following formula was used to determine inbreeding depression as a percentage change in the mean value of F2 relative to F1: -

ID in per cent = $\frac{F1-F2}{F1} \times 100$

Where,
F1 and F2 represent the averages obtained from replications of a specific cross

3.6.4 Estimation of Heritability and Genetic Advance

The narrow sense heritability (h^2n) was determined following the methods proposed by Kempthorne and Curnow (1961).

$$Heritabiliy(h^2n) = \frac{2\sigma^2 g}{2\sigma^2 g + \sigma^2 s + \sigma^2 e} \times 100$$

The formula proposed by Hanson (1963) was utilized in order to determine heritability in wide meaning (h^2b).

$$h^2 b = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

In order to calculate the genetic advance (Ga), the formula that was provided by Johnson et al. (1955) was utilised.

$$Genetic\ advance(GA) = h_b^2.K.\sigma_p$$

$$Genetic\ advance\ in\ per\ cent\ of\ mean = \frac{Ga}{\bar{x}} \times 100$$

CHAPTER 4

Result and Discussion

The complete set of experimental findings for the current study entitled "Genetic evaluation of genotypes in different agro-climatic zones of India for drought tolerance in wheat (*Triticum aestivum* L.)" is arranged under the following heading:

4.1. Estimates of components of variances

4.2. Analysis of variance for combining ability

4.3. Estimates of combining ability

4.4. Estimates of heterosis in F1 generation and Inbreeding depression in F2 generation

4.5. Heritability and genetic advancement in both generations

4.1. Estimates of components of variances

The specific combining ability variances (σ2sca) estimates were higher than general combining ability variances (σ2gca) for all the traits in both Punjab and Meerut except for no. of grains per spike in Meerut, Uttar Pradesh, where σ2sca (-69.42) was lower than σ2gca (Table 4.1.1 and 4.1.2).

Table 4.1.1 Estimates of genetic variances and heritability in F1 generation Punjab

Components of variance	DTF	DTM	PH (cm)	NSPS	NGPS	1000 SW (g)	GYP	SL (cm)	NTPP	HI	BY
σ^2gca	14.44	0.068	60.87	0.19	17.50	9.35	7.30	0.35	5.10	6.979	141.64
σ^2sca	20.19	1.18	214.99	2.28	89.98	33.87	37.21	0.73	25.93	21.46	289.27
σ^2a	28.89	0.13	121.75	0.39	35.00	18.71	14.60	0.70	10.21	13.95	283.28
σ^2D	20.19	1.18	214.99	2.28	89.98	33.87	37.21	0.73	25.93	21.46	289.27
GCA/SCA	0.71	0.05	0.28	0.08	0.19	0.27	0.19	0.47	0.19	0.32	0.48
$H^2_{n.s}$	0.58	0.08	0.36	0.13	0.27	0.35	0.28	0.48	0.28	0.39	0.49

DTF=Days to 75% flowering; DTM= Days to maturity; PH= Plant height; NSPS=No. of spikelets/spike; NGPS= No. of grains/plant; 1000SW= 1000 seeds weight; GYP= Grain yield/plant; SL=spike length; NTPP= No .of tillers/plant; HI=Harvesting index; BY=Biological yield

The estimates of σ2A were positive in magnitude for all of the traits. For every attribute in Punjab and Meerut, Uttar Pradesh, σ2D was higher than σ2A, except for days to 75% flowering in both and no. of spikelets/spike in U.P. where σ2A was higher than σ2D. Traits like days to 75% flowering, plant height, 1000-seeds weight, spike length, harvesting index, and biological yield showed the high narrow-sense heritability estimates (>30%) in both Punjab as well as Meerut, Uttar Pradesh trials.

Table 4.1.2 Estimates of genetic variances and heritability in F1 generation Uttar Pradesh

Components of variance	DTF	DTM	PH (cm)	NSPS	NGPS	1000 SW (g)	GYP	SL (cm)	NTPP	HI	BY
σ^2gca	14.48	0.04	60.75	0.21	80.76	9.18	7.40	0.34	5.14	6.88	141.63
σ^2sca	20.14	0.92	214.93	2.35	-69.42	33.27	36.64	0.78	25.93	21.25	290.80
σ^2a	29.75	0.09	121.51	0.42	161.53	18.37	14.81	0.69	10.29	13.76	283.27
σ^2D	20.14	0.92	214.93	2.35	-69.42	33.27	36.64	0.78	25.93	21.25	290.80
GCA/SCA	0.73	0.05	0.28	0.08	-1.16	0.27	0.20	0.47	0.19	0.32	0.48
$H^2_{n.s}$	0.59	0.07	0.36	0.14	0.27	0.35	0.28	0.46	0.28	0.39	0.49

DTF=Days to 75% flowering; DTM= Days to maturity; PH= Plant height; NSPS=No. of spikelets/spike; NGPS= No. of grains/plant; 1000SW= 1000 seeds weight; GYP= Grain yield/plant; SL=spike length; NTPP= No .of tillers/plant; HI=Harvesting index; BY=Biological yield

4.2 Analysis of variance for combining ability

The experimental material 45 F_1s along with 10 parents were examined under drought stress conditions. For every studied attribute in Punjab and Meerut, Uttar Pradesh trials, the ANOVA results for Treatment, Parents (apart from days to maturity), and hybrids showed high significance (Table 4.2.1 and 4.2.2). For each attribute under study, there were notable variations in the mean squares between the parent vs. hybrid components.

Table 4.2.1 Analysis of variance for combining ability F1 generation in Punjab

	DF	DTF	DTM	PH	NSPS	NGPS	1000SW	GYP
Replicates	2	0.30	3.39*	3.43**	0.41	1.81*	2.64**	2.20**
Treatments	54	137.71***	4.24***	903.24***	7.45***	330.44***	141.27***	137.26***
Parents	9	215.71***	1.46	281.66***	3.72***	53.83***	75.08***	29.31***
Hybrids	44	120.53***	4.73***	1048.23***	8.28***	388.82***	156.65***	160.50***
Parent Vs.Hybrids	1	191.42***	7.57**	117.85***	4.60**	251.34***	60.18***	86.20***
Error	108	0.52	0.87	0.48	0.56	0.47	0.43	0.41
Total	164	45.69	2.01	297.76	2.83	109.13	46.83	45.49
GCA	9	173.55***	1.11***	730.70***	2.53***	210.18***	112.43***	87.76***
SCA	45	20.37***	1.47***	215.15***	2.47***	90.14***	34.02***	37.35***
Error	108	0.17	0.29	0.16	0.188	0.15	0.14	0.13

DTF=Days to 75% flowering; DTM= Days to maturity; PH= Plant height; NSPS=No. of spikelets/spike; NGPS= No. of grains/plant; 1000SW= 1000 seeds weight; GYP= Grain yield/plant;

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	DF	SL	NTPP	HI	BY
Replicates	2	0.04**	1.86**	0.67	2.37*
Treatments	54	3.97***	95.86***	96.00***	1573.53***
Parents	9	4.77***	40.28***	65.50***	739.64***
Hybrids	44	3.81***	105.79***	104.27***	1774.39***
Parent Vs.Hybrids	1	4.04***	159.37***	7.01***	240.98***
Error	108	0.008	0.37	0.46	0.50
Total	164	1.31	31.83	31.92	518.48
GCA	9	4.24***	61.43***	83.90***	1699.87***
SCA	45	0.74***	26.06***	21.62***	289.44***
Error	108	0.003	0.12	0.15	0.16

SL=spike length; NTPP= No .of tillers/plant; HI=Harvesting index; BY=Biological yield
*Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

Table 4.2.2 Analysis of variance for combining ability F1 generation in Meerut, U.P.

	DF	DTF	DTM	PH	NSPS	NGPS	1000SW	GYP	SL
Replicates	2	0.02	3.22*	4.27**	0.27	1547.84	3.80**	1.57	0.04**
Treatments	54	140.36***	3.38***	902.47***	7.81***	1769.71	138.89***	136.59***	4.03***
Parents	9	217.27***	1.42	278.86***	3.94***	7678.45***	74.85***	27.25***	5.39***
Hybrids	44	123.74***	3.75***	1047.94***	8.63***	388.80	153.92***	160.05***	3.81***
Parent Vs.Hybrids	1	179.42***	4.37*	114.30***	6.50**	9351.14*	54.08***	88.26***	1.52***
Error	108	0.72	0.78	0.59	0.66	1458.66	0.56	0.53	0.008
Total	164	46.69	1.66	297.60	3.01	1562.17	46.15	45.34	1.33
GCA	9	178.78***	0.84**	729.30***	2.74***	1455.45**	110.46***	89.05***	4.15***
SCA	45	20.38***	1.18***	215.12***	2.57***	416.79	33.46***	36.82***	0.78***
Error	108	0.243	0.26	0.19	0.22	486.22	0.18	0.17	0.00

DTF=Days to 75% flowering; DTM= Days to maturity; PH= Plant height; NSPS=No. of spikelets/spike; NGPS= No. of grains/plant; 1000SW= 1000 seeds weight; GYP= Grain yield/plant; SL=spike length;
*Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

Significant differences were observed in the GCA and SCA variations for each attribute in F1 of Punjab and Meerut, Uttar Pradesh, indicating the influence of both additive and non-additive genes in each attribute.

Conti…

	DF	NTPP	HI	BY
Replicates	2	3.11**	0.698	3.79**
Treatments	54	96.35***	95.07***	1577.61***
Parents	9	40.96***	65.12***	727.26***
Hybrids	44	106.46***	103.17***	1781.67***
Parent Vs.Hybrids	1	149.79***	8.19***	251.92***
Error	108	0.62	0.63	0.78
Total	164	32.17	31.73	520.01
GCA	9	61.97***	82.81***	1699.90***
SCA	45	26.14***	21.46***	291.06***
Error	108	0.21	0.21	0.26

NTPP= No .of tillers/plant; HI=Harvesting index; BY=Biological yield *Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

4.3 Estimation of combining ability effects in F1 generation in Punjab and Meerut, Uttar Pradesh

The outputs of General combining ability as well as specific combining ability effects of 10 parents along with 45 F_1s for all the studied attributes are given in Table 4.3.1 ,4.3.2, 4.3.3, and 4.3.4.

4.3.1 Days to 75% flowering

Negative GCA and SCA effects indicate that early flowering in wheat is preferable. Therefore, it is ideal to have parents and crosses that have negative significant GCA and SCA effects. In the F1 generation, five parents in Punjab, and five in the Uttar Pradesh environment showed notably favorable GCA effects. The parental lines IC138866, IC55681, IC78801, IC75310, and IC75310 exhibited notably favorable GCA effects in both settings in F1 generations. Therefore, these parents were regarded as proficient in crossbreeding to achieve 75% flowering within a specific time frame. On the other hand, parent IC212140, IC532889, IC82322, IC78751, and IC78737 exhibited notable positive GCA impacts, indicating their limited ability to combine well for days to 75% blooming (Table 4.3.1 and Table 4.3.3). The findings moreover demonstrated that 17 crosses in Punjab and 18 crosses in Meerut, Uttar Pradesh displayed noteworthy adverse SCA outcomes. The crossovers IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC532889×IC82322, IC532889×IC78751, IC532889×IC78737, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC78751×IC78737, IC138866×IC78737, IC138866×IC75310, IC138866×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310 with exception of IC78801×IC75310 (in Meerut, Uttar Pradesh) had a strong negative SCA effect in both Punjab and Meerut, Uttar Pradesh. Consequently, these crosses are deemed to be desirable crosses.

Table 4.3.1 Estimates of General combining ability and Specific combining in F_1 generation for Days to 75% flowering, Days to Maturity, Plant Height, No. of spikelets/spike, and No. of grains /spike in Punjab

Parent	Days to 75% flowering (n)	Days to maturity (n)	Plant height (cm)	No. of spikelets /spike (n)	No. of grains /spike (n)
GENERAL COMBINING ABILITY					

IC212140	4.27***	-0.106	1.26***	-0.39**	2.70***
IC532889	4.36***	-0.106	-19.72***	-0.36**	1.25***
IC82322	2.22***	-0.133	7.88***	-0.200	5.42***
IC78751	3.30***	0.006	9.36***	0.41***	-9.18***
IC138866	-3.69***	-0.522***	-1.34***	0.63***	4.95***
IC78737	2.50***	-0.161	1.17***	-0.33**	-1.93***
IC55681	-5.47***	-0.133	-1.33***	-0.56***	-1.07***
IC78801	-4.83***	0.394**	0.76***	-0.14	0.70***
IC75310	-1.66***	0.506***	0.90***	0.68***	-0.68***
IC75310	-1.00***	0.256	1.04***	0.27*	-2.13***
Crosses	SPECIFIC COMBINING ABILITY				
IC212140×IC532889	1.87 ***	-1.60 **	14.33 ***	-0.76	3.92 ***
IC212140×IC82322	-1.31 **	-0.24	-31.94 ***	-0.59	2.42 ***
IC212140×IC78751	-4.06 ***	-0.37	15.24 ***	-1.20 **	6.37 ***
IC212140×IC138866	9.26 ***	-0.51	15.28 ***	0.57	-1.76 ***
IC212140×IC78737	-3.59 ***	-0.21	-16.23 ***	0.87 *	5.45 ***
IC212140×IC55681	3.04 ***	2.42 ***	11.77 ***	0.10	-15.40 ***
IC212140×IC78801	3.07 ***	0.23	-2.48 ***	1.01 *	-0.84 *
IC212140×IC75310	-0.76	1.12 *	-3.66 ***	0.51	2.87 ***
IC212140×IC75310	1.23 **	-0.96	10.89 ***	0.93 *	-4.68 ***
IC532889×IC82322	-1.73 ***	-0.24	2.04***	-1.28 **	-4.79 ***
IC532889×IC78751	-5.15 ***	-0.37	29.90 ***	-1.23 **	15.81 ***
IC532889×IC138866	4.18 ***	1.81 ***	-21.89 ***	2.21***	16.01 ***
IC532889×IC78737	-1.67 ***	1.12 *	-5.27 ***	1.18 **	-1.09 **
IC532889×IC55681	5.96***	-0.90	-0.628	-0.92 *	-5.96 ***
IC532889×IC78801	1.32 **	-0.10	-12.42 ***	0.65	-6.07 ***
IC532889×IC75310	-1.17 **	1.12 *	-14.30 ***	-2.17***	-4.01 ***
IC532889×IC75310	2.82 ***	-0.96	-37.94 ***	-0.09	-5.23 ***
IC82322×IC78751	-4.34 ***	-2.01 ***	-4.64 ***	-1.39**	7.65 ***
IC82322×IC138866	3.65 ***	-0.49	20.66 ***	0.71	8.51 ***
IC82322×IC78737	-3.20 ***	1.81 ***	3.64 ***	0.68	-6.93 ***
IC82322×IC55681	5.76 ***	0.45	2.52 ***	-0.42	-8.46 ***
IC82322×IC78801	4.12 ***	-0.40	3.22 ***	1.15**	8.76 ***
IC82322×IC75310	-0.04	0.06	5.08 ***	0.65	1.48 ***
IC82322×IC75310	0.96*	0.06	-1.12 **	0.74	-5.40 ***
IC78751×IC138866	5.23 ***	1.37 **	-0.54	-2.89***	-7.21 ***
IC78751×IC78737	-2.95 ***	-0.65	16.66 ***	0.07	-8.65 ***
IC78751×IC55681	6.01 ***	0.64	-11.48 ***	2.29 ***	-13.51 ***
IC78751×IC78801	3.04 ***	-0.54	-6.24***	2.54 ***	-10.96 ***

IC78751×IC75310	3.54 ***	-1.32 *	-22.39 ***	-0.95*	-13.90 ***
IC78751×IC75310	3.54 ***	0.92	14.50 ***	1.462***	-13.46 ***
IC138866×IC78737	-7.29 ***	-2.12 ***	2.038 ***	-0.81 *	-1.79 ***
IC138866×IC55681	0.34	-2.82 ***	9.22 ***	-0.92 *	-4.32 ***
IC138866×IC78801	-0.62	-0.35	-19.37***	-1.34**	-14.43 ***
IC138866×IC75310	-3.12 ***	1.53 **	-5.69 **	0.82 *	14.95 ***
IC138866×IC75310	-5.45 ***	-0.51	-2.69 ***	3.24 ***	12.06 ***
IC78737×IC55681	7.82***	-0.51	-13.86 ***	2.37***	7.56 ***
IC78737×IC78801	5.18 ***	0.62	-11.10 ***	-3.70 ***	6.45 ***
IC78737×IC75310	2.34 ***	-1.15 *	2.78***	3.12 ***	-8.48 ***
IC78737×IC75310	2.34 ***	0.76	11.64 ***	-1.45 ***	-3.37 ***
IC55681×IC78801	-4.17 ***	-0.07	1.11 **	-0.48	2.59 ***
IC55681×IC75310	-7.34 ***	0.81	7.40 ***	-0.98 *	9.65 ***
IC55681×IC75310	-9.67 ***	-1.60 **	-5.83 ***	-0.89 *	11.76 ***
IC78801×IC75310	2.01 ***	1.28 *	14.20 ***	1.93 ***	10.20 ***
IC78801×IC75310	-0.98 *	0.53	4.39***	0.018	-2.68 ***
IC75310×IC75310	2.84***	-1.24 *	15.25 ***	-1.81 ***	-7.29 ***

*Significance $P \leq 0.05$; **Significance $P \leq 0.01$; ***Significance $P \leq 0.001$

4.3.2 Days to Maturity

Wheat with early maturity is considered favourable, as indicated by the presence of negative GCA and SCA impacts. Therefore, the parents and crosses with negative substantial GCA and SCA effects are preferred.

The only parent, IC138866, in the Punjab and Meerut, Uttar Pradesh environment had shown a negative significant GCA impact. Therefore, this parent was regarded as an excellent overall cross breeder in terms of the time it takes for the offspring to achieve maturity. Additional comparison between the environments revealed that, with the exception of the IC138866 parent, all other parents demonstrated a substantial positive GCA effect, indicating their limited ability to combine well for days to maturity.

In the F1 generation, eight crosses in Punjab, and nine crosses in Meerut, Uttar Pradesh exhibited substantial unfavourable SCA impacts. The crosses IC212140×IC532889, IC82322×IC78751, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC78737×IC75310, IC55681×IC75310, IC75310×IC75310 in Punjab and IC212140×IC532889, IC532889×IC75310, IC82322×IC78751, IC82322×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC55681×IC75310, IC75310×IC75310 in Meerut, Uttar Pradesh exhibited negative significant SCA effects. Therefore, these crosses are considered as desirable (Table 4.3.1 and 4.3.3).

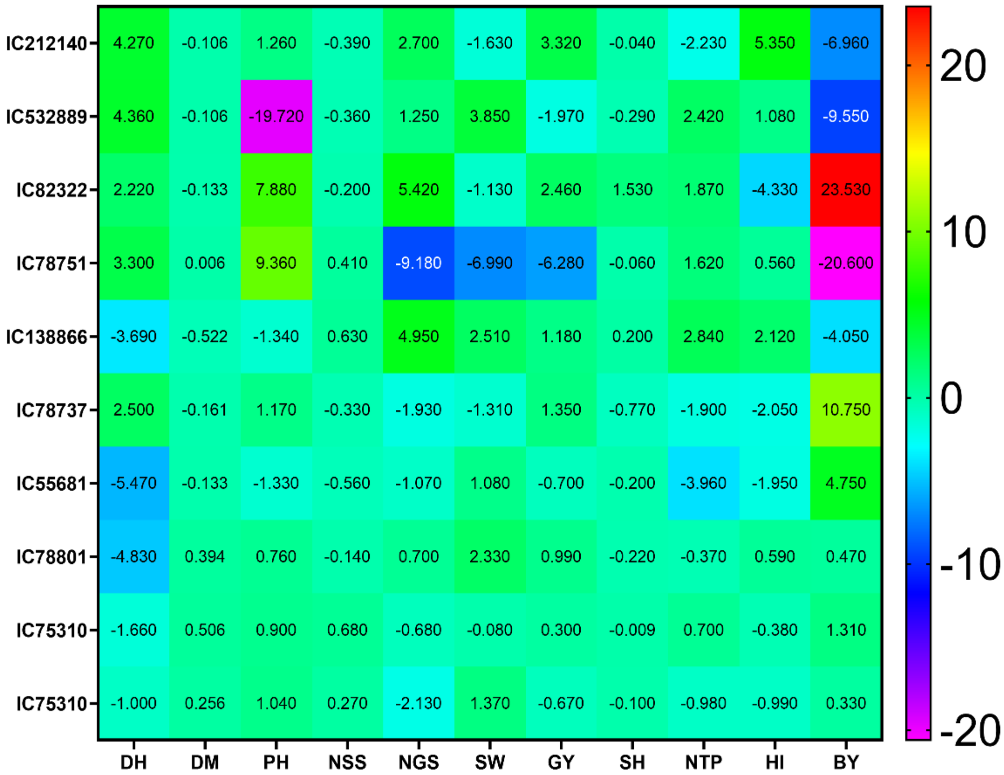

Figure 4.3.1. A heatmap depicting the GCA (Punjab) with parents on the vertical axis and 11 traits on the horizontal axis. The red and purple/blue colors indicate negative and positive values of combining ability.

4.3.3 Plant height

Medium height in wheat is preferred, as indicated by negative GCA and SCA impacts. Therefore, the parents and crosses exhibited negative substantial GCA and SCA effects are preferable.

Three parental lines in Punjab and Meerut, Uttar Pradesh exhibited negative substantial GCA impacts in the F1 generation. Parent IC532889 and IC138866 in both settings, had highly favourable GCA impacts and was regarded as an excellent overall cross breeder for plant height. Subsequent comparison among the environments revealed that the parent IC212140, IC82322, IC78751, IC78737, IC78801, IC75310, and IC75310 had a substantial positive GCA effect, indicating their inferior general combining capacity for plant height. In the F1 generation, 20 crosses in both Punjab and Meerut, Uttar Pradesh, demonstrated significantly negative SCA impacts. The crosses IC212140×IC82322, IC212140×IC78737,

IC212140×IC78801, IC212140×IC75310, IC532889×IC138866, IC532889×IC78737, IC532889×IC78801, IC532889×IC75310, IC532889×IC75310, IC82322×IC78751, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC55681×IC75310 in Punjab and Meerut, Uttar Pradesh exhibited consistently noteworthy SCA effects, thus deemed favourable crosses (Table 4.3.1 and 4.3.3).

4.3.4 No. of spikelets /spike

No. of spikelets /spike is a beneficial parameter for yield enhancement, correlated with favorable GCA and SCA effects. Consequently, the parents and crosses exhibiting significant positive GCA and SCA impacts are preferred. Four parents in Punjab and three parents in Meerut, Uttar Pradesh had strong positive GCA impacts. The parent IC78751, IC138866, and IC75310 in both the settings (Punjab and Meerut, Uttar Pradesh), whereas IC75310 in Punjab had extremely acceptable GCA effects, therefore may be considered effective general combiner for no. of spikelets per spike. A comparison analysis of the environments revealed that the parent IC212140, IC532889, IC82322, IC78737, IC55681, and IC78801 in Punjab as well as the parent IC212140, IC532889, IC82322, IC78737, IC55681, IC78801, and IC75310 exhibited unfavorable GCA effects indicating their inadequate general combining ability for no. of spikelets /spike (refers to Table 4.3.1 and 4.3.3).

In the F1 generation, 14 crosses demonstrated strong noteworthy SCA impacts in Punjab, whereas 13 crossings exhibited similar effects in Meerut, Uttar Pradesh.

The IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC532889×IC138866, IC532889×IC78737, IC82322×IC78801, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, and IC78801×IC75310 in both settings, except IC212140×IC78737 (in Punjab), IC82322×IC138866, exhibited unfavorable SCA impacts, therefore deemed undesirable for this trait.

4.3.5 Number of grains per spike

Positive GCA and SCA effects are associated with an increased grains count per spike,which is regarded as advantageous for a higher grain yield. Consequently, it is advisable to select the parents and crosses that exhibit notable positive GCA and SCA impacts. In the F1

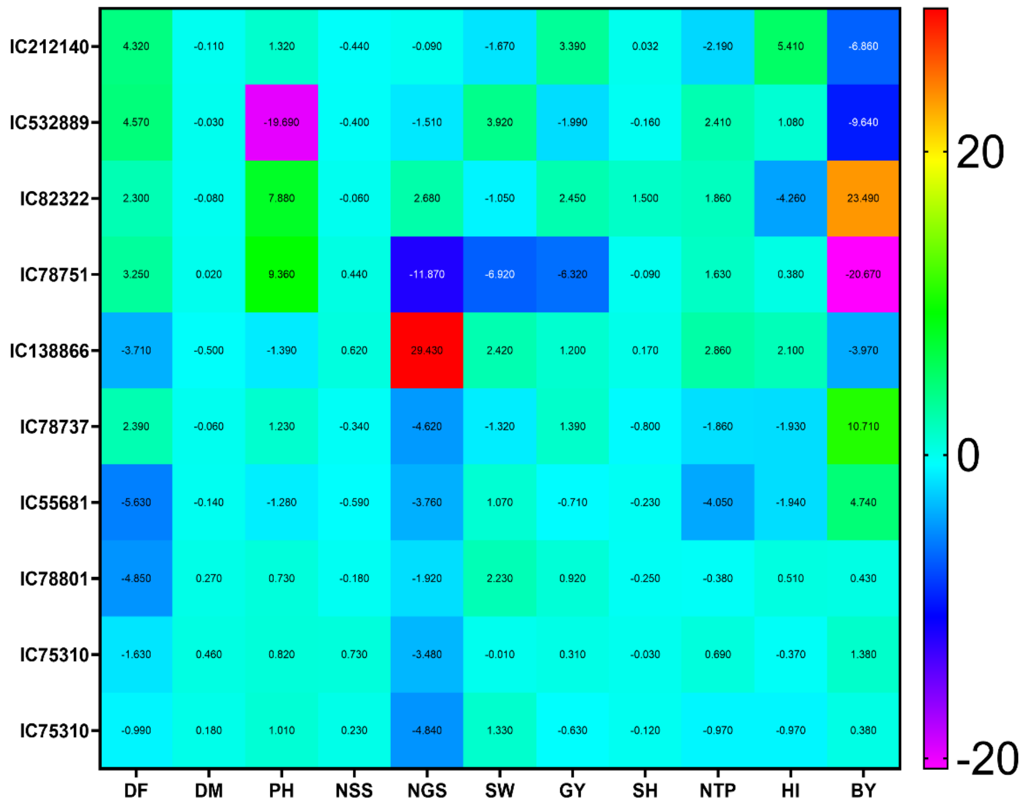

Figure 4.3.2. A heatmap depicting the GCA (U.P.) with parents on the vertical axis and 11 traits on the horizontal axis. The red and purple/blue colors indicate negative and positive values of combining ability.

generation, five parents in Punjab and one parent in the Meerut, Uttar Pradesh exhibited strong favorable GCA effects. The parents IC212140, IC532889, IC82322, IC138866, and IC78801 in the Punjab along with IC138866 in Meerut, Uttar Pradesh, had highly favorable GCA effects and may therefore be considered as effective general combiner for the number of grains per spike. A comparison analysis across the settings revealed that the IC78751, IC78737, IC55681, IC75310, and IC75310 in the Punjab trial, as well as all the parents except IC138866 in Meerut, Uttar Pradesh demonstrated unfavorable GCA effects, indicating their inferior general combining ability for the number of grains per spike.

In Punjab trial, nineteen crosses exhibited noteworthy positive SCA effects whereas in Meerut, Uttar Pradesh all exhibited unfavourable SCA effects. The combinations of IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC78801, IC532889×IC82322, IC532889×IC78751, IC82322×IC78751, IC82322×IC138866, IC82322×IC75310, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, and IC78801×IC75310 exhibited statistically significant SCA effects, and are thus deemed favourable crosses overs. In Meerut, Uttar Pradesh 17 crosses had a positive but non-significant SCA effect, therefore deemed unfavorable for this trait (Table 4.3.1. and 4.3.3).

4.3.6 1000-grain weight

Positive GCA and SCA impacts are desirable for this trait. Therefore, parents and crosses exhibiting significant positive GCA and SCA effects are preferable. In the F1 generation, five parental lines from both Punjab and Meerut, Uttar Pradesh exhibited strong favorable general combining ability impacts. The parents IC532889, IC138866, IC55681, IC78801, and IC75310 in both settings exhibited favourable GCA effects and may be regarded as effective general combiners for 1000-grain weight. A comparative analysis of the environments showed that parent IC212140, IC82322, IC78751, IC78737, and IC75310 had a substantial negative general combining ability effect for 1000-grain weight in both environments, indicating their worse performance in this regard.

Twenty crosses in Punjab and nineteen crosses in Meerut, Uttar Pradesh had statistically significant SCA effects. The crosses overs IC212140×IC82322, IC212140×IC78751, IC212140×IC55681, IC532889×IC78751, IC532889×IC78737, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC55681, IC138866×IC78737, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 in both settings, except for IC138866×IC75310 (in Meerut, Uttar Pradesh), exhibited significant positive SCA effects and are therefore deemed desirable crosses (Tables 4.3.2 and 4.3.4).

Table 4.3.2 Estimates of General combining ability and Specific combining in F_1 generation for 1000 seeds weight, Grain yield/plant, spike height, No. of tillers/plant, Harvesting index, and Biological yield in Punjab

Parent	1000 seeds weight (gm)	Grain yield/plant (gm)	Spike height (cm)	No. of tillers /plant (n)	Harvesting index (%)	Biological Yield (g)
GENERAL COMBINING ABILITY						
IC212140	-1.63***	3.32***	-0.04***	-2.23***	5.35***	-6.96***

IC532889	3.85***	-1.97***	-0.29***	2.42***	1.08***	-9.55***
IC82322	-1.13***	2.46***	1.53***	1.87***	-4.33***	23.53***
IC78751	-6.99***	-6.28***	-0.06***	1.62***	0.56***	-20.60***
IC138866	2.51***	1.18***	0.20***	2.84***	2.12***	-4.05***
IC78737	-1.31***	1.35***	-0.77***	-1.90***	-2.05***	10.75***
IC55681	1.08***	-0.70***	-0.20***	-3.96***	-1.95***	4.75***
IC78801	2.33***	0.99***	-0.22***	-0.37***	0.59***	0.47***
IC75310	-0.08	0.30**	-0.009***	0.70***	-0.38***	1.31***
IC75310	1.37***	-0.67***	-0.10***	-0.98***	-0.99***	0.33***
Crosses	**SPECIFIC COMBINING ABILITY**					
IC212140×IC532889	-0.19	-2.08 ***	-0.009	-5.20 ***	-1.79 ***	0.28
IC212140×IC82322	6.79**	3.80 ***	-0.26 ***	-6.65 ***	10.76 ***	-25.13 ***
IC212140×IC78751	1.66**	9.88 ***	-0.24 ***	-6.73 ***	10.56 ***	4.66***
IC212140×IC138866	-0.85	-1.58 ***	-0.307***	-6.95 ***	-9.66 ***	25.11 ***
IC212140×IC78737	-0.76	2.91 ***	1.10 ***	6.46 ***	-0.40	5.97 ***
IC212140×IC55681	4.58**	0.63	0.00	0.18	4.27***	-11.35 ***
IC212140×IC78801	-0.34	3.27 ***	0.08	4.93 ***	3.42***	-1.08 ***
IC212140×IC75310	-2.25**	0.97 **	0.27 ***	10.18 ***	0.04	1.75 ***
IC212140×IC75310	-5.55**	2.27 ***	-0.06	6.21 ***	-1.55 ***	9.72 ***
IC532889×IC82322	-2.95**	-2.88 ***	-1.62 ***	-6.65 ***	0.94 *	-15.55
IC532889×IC78751	4.51**	7.86 ***	-0.55 ***	7.93***	-1.00 **	25.25
IC532889×IC138866	-2.00**	-0.27	0.37 ***	5.04 ***	-3.42 ***	9.36
IC532889×IC78737	5.48**	2.55 ***	1.22 ***	0.46	11.19 ***	-23.10
IC532889×IC55681	-5.57**	-0.05	-0.74 ***	0.84 *	3.65 ***	-12.10
IC532889×IC78801	-1.65**	-3.41 ***	-0.83 ***	0.26	-4.62 ***	3.50
IC532889×IC75310	-9.07**	0.94 **	-0.34 ***	4.51 ***	0.79 *	0.00
IC532889×IC75310	2.46**	-2.41 ***	1.04 ***	-2.79 ***	5.30 ***	-19.35
IC82322×IC78751	6.49**	8.75 ***	0.74 ***	10.48 ***	-2.39 ***	34.83
IC82322×IC138866	-5.02**	0.944**	-1.28 ***	7.93 ***	-1.68 ***	6.61
IC82322×IC78737	2.46**	-11.55 ***	-0.10 *	7.01 ***	-7.35 ***	-3.19
IC82322×IC55681	2.41**	2.50 ***	0.69 ***	1.07 **	0.69	4.47
IC82322×IC78801	-1.84**	3.13 ***	0.34 ***	-3.84 ***	-1.56 ***	15.08
IC82322×IC75310	-1.75**	6.16 ***	2.49 ***	0.40	1.33 ***	12.58
IC82322×IC75310	-7.55**	-6.19 ***	1.02 ***	-0.23	-4.28 ***	-2.44
IC78751×IC138866	-7.15**	-10.30 ***	-0.92 ***	0.18	-2.01 ***	-21.91
IC78751×IC78737	-3.99**	-13.13 ***	-0.009	2.93 ***	-3.75 ***	-33.05
IC78751×IC55681	-11.38**	-5.75 ***	0.35***	1.65***	3.32 **	-25.72
IC78751×IC78801	-10.14**	-9.44 ***	0.20 ***	-2.92 ***	-0.19	-25.10
IC78751×IC75310	-3.88**	-11.41 ***	0.15 **	-1.01 **	-2.28 ***	-27.94

IC78751×IC75310	-6.81**	-8.77 ***	1.44 ***	-1.31***	-4.78 ***	-14.97
IC138866×IC78737	2.15**	0.38	0.49 ***	7.37 ***	2.64 **	-8.60
IC138866×IC55681	5.09**	1.77 ***	0.25 ***	4.09 ***	2.52 ***	-4.27
IC138866×IC78801	7.18**	2.41 ***	-0.66 ***	-3.81 ***	1.42 ***	2.00
IC138866×IC75310	0.93	1.44 ***	-0.27 ***	-5.90 ***	1.82 ***	-1.49
IC138866×IC75310	1.66**	0.08	0.84 ***	0.12	0.46	-1.19
IC78737×IC55681	-0.74*	4.94 ***	0.23 ***	-1.81 ***	0.22	13.25
IC78737×IC78801	-6.96***	1.91 ***	-0.14 **	-5.73 ***	-3.28 ***	17.53
IC78737×IC75310	-2.24***	4.61 ***	0.20 ***	-8.15 ***	-0.47	15.03
IC78737×IC75310	-2.70***	5.58 ***	-1.40 ***	-2.79 ***	0.86 *	13.00
IC55681×IC78801	5.61***	-4.02 ***	0.08	-2.01 ***	-4.45 ***	1.53
IC55681×IC75310	6.36***	-2.33 ***	0.16 ***	-2.09 ***	-6.74 ***	19.03
IC55681×IC75310	9.23***	0.30	0.62 ***	-2.40 ***	-3.76 ***	14.66
IC78801×IC75310	6.78 ***	0.30	0.28 ***	4.32 ***	0.83 *	-2.35
IC78801×IC75310	5.98***	2.61 ***	-0.42 ***	4.01 ***	2.42 ***	-0.72
IC75310×IC75310	2.73***	-2.69 ***	-1.20 ***	1.26 ***	-2.41 ***	-0.22

*Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

4.3.7. Grain yield per plant

The parents and crosses exhibiting positive and significant General Combining Ability (GCA) and Specific Combining Ability (SCA) impacts are preferred. In the F1 generation, six parental lines from Punjab and Meerut, Uttar Pradesh exhibited strong positive general combining ability impacts. The parents IC212140, IC82322, IC138866, IC78737, IC78801, and IC75310 showed strong notable GCA impact in both settings. Therefore, these parents were regarded as proficient in crossbreeding to achieve high grain yield per plant. A comparative analysis across the settings demonstrated that parents IC532889, IC78751, IC55681, and IC75310 exhibited a substantial negative general combining ability (GCA) effect in all environments, indicating these parents' inadequate general combining ability for grain production per plant.

Twenty-two crosses in Punjab and nineteen crosses in Meerut, Uttar Pradesh had substantial beneficial SCA effects. The crosses IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310 (exclusive to Punjab), IC212140×IC75310, IC532889×IC78751 (exclusive to Punjab), IC532889×IC78737, IC532889×IC75310 (exclusive to Punjab), IC82322×IC78751, IC82322×IC138866,

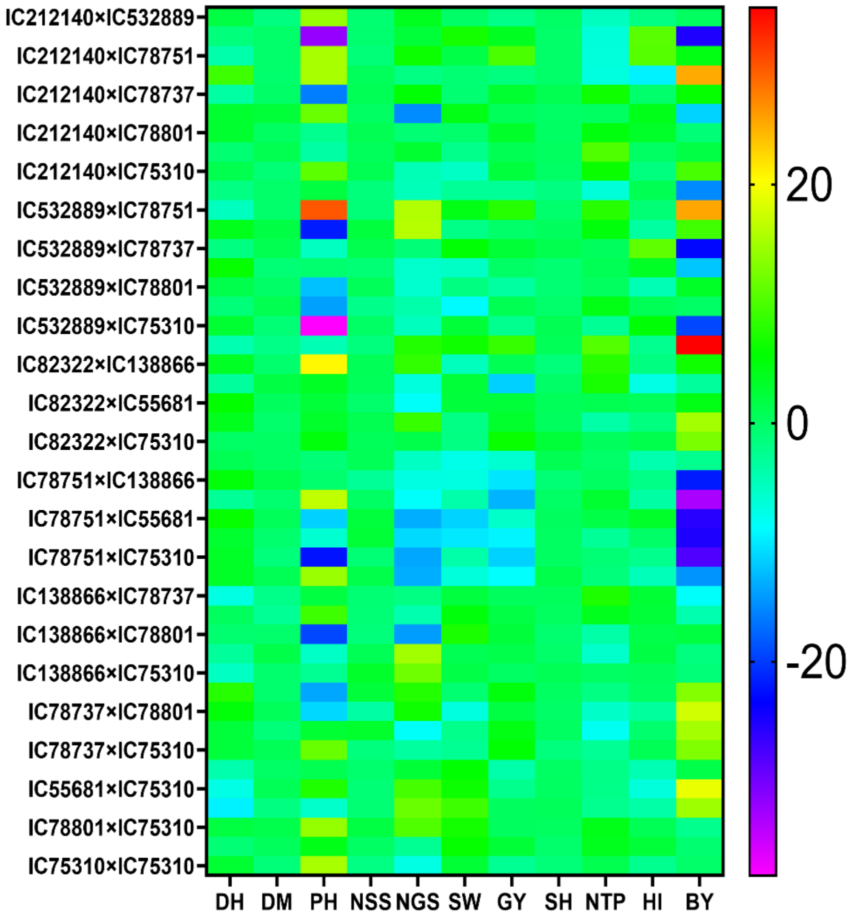

Figure 4.3.3. A heatmap depicting the SCA (Punjab) with hybrids on the vertical axis and 11 traits on the horizontal axis. The yellow and purple/blue colors indicate negative and positive values of combining ability.

IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, and IC78801×IC75310 in both Punjab and Meerut, Uttar Pradesh, exhibited noteworthy SCA impacts, thus deemed as desirable crosses (refer to Tables 4.3.2 and 4.3.4).

4.3.8 Spike length

A longer spike length is considered to be favourable for higher grain yield and is linked with positive GCA and SCA impacts. Therefore, it is desirable to have parents and crosses that exhibit notable GCA and SCA effects.

In the F1 generation, two parents in in trials conducted in Punjab and Meerut, Uttar Pradesh exhibited significant positive GCA effects. The parent IC82322 and IC138866 exhibited favourable GCA effects, indicating their potential as strong general combiners for spike length traits. Additional comparison of the both settings revealed that certain parents in the Punjab and Meerut showed unfavorable GCA impacts for spike length. Specifically, parents IC212140, IC532889, IC78751, IC78737, IC55681, IC78801, IC75310, and IC75310 in Punjab, and IC532889, IC78751, IC78737, IC55681, IC78801, IC75310, and IC75310 in Meerut exhibited inferior general combining ability for spike length (Table 4.3.2 and 4.3.4).

Twenty-two crossings in Punjab and twenty-three crosses in Meerut, Uttar Pradesh exhibited substantial beneficial SCA impacts. The crosses, IC212140×IC78737, IC212140×IC75310, IC532889×IC138866, IC532889×IC78737, IC532889×IC75310, IC82322×IC78751, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC55681×IC75310, IC55681×IC75310, and IC78801×IC75310 showed positive significant SCA effects in both environments, except for IC55681×IC78801 only in Meerut, Uttar Pradesh; thus, these are deemed desirable crosses (Table 4.3.2 and 4.3.4).

4.3.9 Number of tillers per plant

A greater number of tillers per plant is deemed advantageous, and are linked with favourable GCA and SCA impacts. Therefore, it is ideal to have parents and crosses that have significant positive GCA and SCA impacts. In the F1 generation, five parental lines in Punjab and five in the Meerut environment showed notably favourable GCA impacts. The parental lines IC532889, IC82322, IC78751, IC138866, and IC75310 exhibited notably favourable GCA impacts in both settings. Therefore, these parents were considered proficient in crossbreeding for no. of tillers per plant. Additional comparison across the settings revealed that the parent IC212140, IC78737, IC55681, IC78801, and IC75310 exhibited notable negative GCA impacts, indicated their limited ability to combine well for number of tillers per plant.

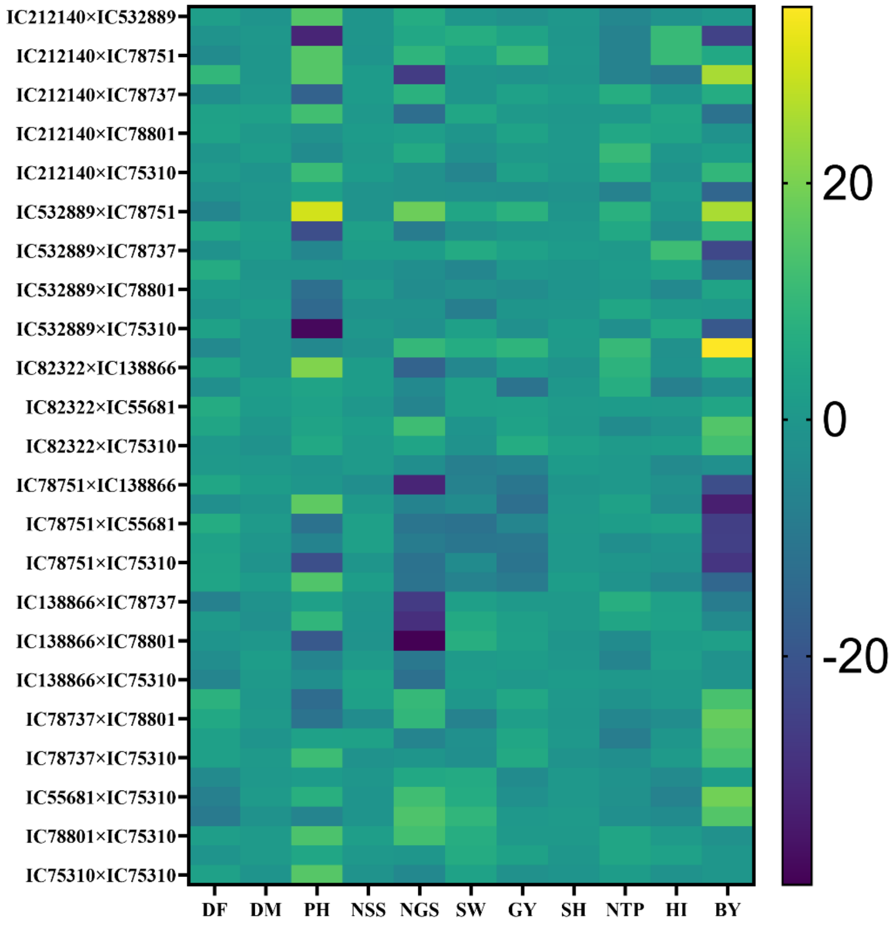

Figure 4.3.4. A heatmap depicting the SCA (U.P.) with hybrids on the vertical axis and 11 traits on the horizontal axis. The yellow and blue colors indicate negative and positive values of combining ability.

Table 4.3.3 Estimates of General combining ability and Specific combining in F_1 generation for Days to 75% flowering, Days to Maturity, Plant Height, No. of spikelets/spike, and No. of grains /spike in Meerut, U.P.

Parent	Days to 75% flowering(n)	Days to maturity (n)	Plant height (cm)	No. of spikelets /spike (n)	No. of grains /spike (n)
GENERAL COMBINING ABILITY					
IC212140	4.32 ***	-0.11	1.32 ***	-0.44 ***	-0.09
IC532889	4.57 ***	-0.03	-19.69 ***	-0.40 **	-1.51
IC82322	2.30 ***	-0.08	7.88 ***	-0.06	2.68
IC78751	3.25 ***	0.02	9.36 ***	0.44 ***	-11.87
IC138866	-3.71 ***	-0.50 **	-1.39 ***	0.62***	29.43 ***
IC78737	2.39 ***	-0.06	1.23 ***	-0.34**	-4.62

IC55681	-5.63 ***	-0.14	-1.28 ***	-0.59***	-3.76
IC78801	-4.85 ***	0.27	0.73 ***	-0.18	-1.92
IC75310	-1.63 ***	0.46**	0.82 ***	0.73***	-3.48
IC75310	-0.99 ***	0.18	1.01 ***	0.23	-4.84
Crosses	SPECIFIC COMBINING ABILITY				
IC212140×IC532889	1.76***	-1.04*	14.86***	-0.77	6.11
IC212140×IC82322	-1.48**	-0.32	-32.06***	-0.77	4.91
IC212140×IC78751	-4.09***	-0.43	15.13***	-1.12*	8.80
IC212140×IC138866	9.55***	-0.57	15.22***	0.87	-26.50
IC212140×IC78737	-3.23***	-0.01	-16.41***	0.84	7.89
IC212140×IC55681	3.14***	2.41***	12.27***	0.09	-12.98
IC212140×IC78801	3.36***	0.32	-2.24***	1.00*	1.86
IC212140×IC75310	-0.87	1.13*	-4.03***	0.42	5.41
IC212140×IC75310	0.83	-0.93	10.81***	0.92	-2.23
IC532889×IC82322	-1.73***	-0.40	2.63***	-1.48**	-2.34
IC532889×IC78751	-5.34***	-0.84	29.82***	-1.33**	18.22
IC532889×IC138866	4.30***	1.68***	-21.92***	2.16***	-8.75
IC532889×IC78737	-1.81***	0.91	-5.42***	1.13*	1.30
IC532889×IC55681	5.89***	-0.68	-0.77	-0.96*	-3.23
IC532889×IC78801	1.11*	-0.09	-12.82***	0.63	-3.73
IC532889×IC75310	-1.12*	1.05*	-14.31***	-1.96***	-1.50
IC532889×IC75310	2.91***	-1.01*	-38.01***	-0.46	-2.48
IC82322×IC78751	-4.41***	-1.12*	-4.70***	-1.66***	10.03
IC82322×IC138866	3.57***	-0.93	20.66***	1.16*	-16.28
IC82322×IC78737	-2.88***	1.63***	3.53***	1.13*	-4.56
IC82322×IC55681	5.82***	1.058	2.74***	-0.29	-6.09
IC82322×IC78801	4.04***	-0.37	3.53***	1.63***	11.75
IC82322×IC75310	0.15	-1.57***	5.10***	0.71	3.97
IC82322×IC75310	0.51	0.05	-1.16**	0.55	-3.00
IC78751×IC138866	4.62***	1.30**	-0.54	-3.02***	-32.06
IC78751×IC78737	-2.82***	-0.82	16.55***	0.28	-6.34
IC78751×IC55681	6.20***	0.60	-11.60***	2.53***	-10.53
IC78751×IC78801	3.09***	-0.48	-6.28***	2.45***	-8.70
IC78751×IC75310	3.54***	-1.34**	-21.70***	-0.80	-11.48
IC78751×IC75310	3.90***	0.93	14.47***	1.69***	-11.11
IC138866×IC78737	-7.18***	-1.62**	2.31***	-0.90*	-26.64
IC138866×IC55681	0.51	-2.54***	9.16***	-0.98*	-29.50
IC138866×IC78801	-0.93*	-0.29	-19.02***	-1.40***	-39.34
IC138866×IC75310	-3.49***	1.52**	-5.95***	0.68	-9.78

IC138866×IC75310	-5.80***	0.46	-3.01***	3.18***	-12.42
IC78737×IC55681	8.06***	-0.32	-13.71***	2.32***	10.22
IC78737×IC78801	4.96***	0.27	-11.19***	-3.76***	9.39
IC78737×IC75310	2.40***	-0.93	2.76***	2.99***	-6.06
IC78737×IC75310	2.43***	0.35	11.56***	-1.51**	-0.70
IC55681×IC78801	-4.35***	0.02	1.03*	-0.51	5.19
IC55681×IC75310	-7.57***	0.82	7.37***	-1.09*	12.08
IC55681×IC75310	-9.21***	-1.57**	-5.92***	-0.93*	14.11
IC78801×IC75310	1.98***	0.74	13.92***	1.82***	12.58
IC78801×IC75310	-0.99*	0.68*	4.39***	-0.01	-0.39
IC75310×IC75310	2.79***	-1.18*	15.31***	-1.26**	-4.84

*Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

In the F1 generation, 19 crosses in both Punjab and Meerut, Uttar Pradesh displayed noteworthy adverse SCA outcomes. The crossovers IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC78751×IC78737, IC78751×IC55681, IC138866×IC78737, IC138866×IC55681, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 had a strong positive SCA impacts in both Punjab and Meerut, Uttar Pradesh. Consequently, these crosses are deemed to be desirable crosses (Table 4.3.2 and 4.3.4).

4.3.10 Harvest index

Positive GCA and SCA impacts are deemed desirable for this trait. Therefore, the parents and crosses exhibited positive substantial GCA and SCA effects are preferable.

Five parental lines in Punjab and Meerut, Uttar Pradesh exhibited positive substantial GCA impacts in F1 generation. Therefore, theses parents were considered as excellent overall cross breeder for harvest index. Subsequent comparison among the both settings showed that the parent IC212140. IC532889, IC78751, IC138866, and IC78801 had substantial positive GCA impact. Whereas, parents IC82322, IC78737, IC55681, IC75310, and IC75310 displayed inferior general combining capacity for harvest index (Table 4.3.2 and 4.3.4).

In Punjab trial, eighteen crosses exhibited noteworthy positive SCA effects whereas and in Meerut, Uttar Pradesh fourteen crosses exhibited favourable SCA effects. The combinations of IC212140×IC82322, IC212140×IC78751, IC212140×IC55681, IC212140×IC78801, IC532889×IC82322 (in Punjab only), IC532889×IC78737, IC532889×IC55681, IC532889×IC75310 (in Punjab only), IC532889×IC75310, IC82322×IC75310, IC78751×IC55681, IC138866×IC78737, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC78737×IC75310 (in Punjab only), IC78801×IC75310 (in Punjab only), and IC78801×IC75310 had statistically significant SCA effects, and thus deemed favourable crosses (Table 4.3.2 and 4.3.4).

Table 4.3.4 Estimates of General combining ability and Specific combining in F_1 generation for 1000 seeds weight, Grain yield/plant, spike height, No. of tillers/plant, Harvesting index, and Biological yield in Meerut, U.P.

Parent	1000 seeds weight (gm)	Grain yield/plant (gm)	Spike height (cm)	No. of tillers /plant (n)	Harvesting index (%)	Biological Yield (g)
GENERAL COMBINING ABILITY						
IC212140	-1.67 ***	3.39 **	0.032	-2.19**	5.41 ***	-6.86 ***
IC532889	3.92 ***	-1.99 **	-0.16**	2.41**	1.08 ***	-9.64 ***
IC82322	-1.05 ***	2.45 **	1.50**	1.86**	-4.26 ***	23.49 ***
IC78751	-6.92 ***	-6.32 **	-0.09**	1.63**	0.38 **	-20.67 ***
IC138866	2.42 ***	1.20 **	0.17**	2.86**	2.10 ***	-3.97 ***
IC78737	-1.32 ***	1.39 **	-0.80**	-1.86**	-1.93 ***	10.71 ***
IC55681	1.07***	-0.71**	-0.23**	-4.05**	-1.94 ***	4.74 ***
IC78801	2.23 ***	0.92 **	-0.25**	-0.38*	0.51 ***	0.43 **
IC75310	-0.01 ***	0.31*	-0.03	0.69**	-0.37 **	1.38 ***
IC75310	1.33 ***	-0.63 **	-0.12**	-0.97**	-0.97 ***	0.38 **
Crosses	**SPECIFIC COMBINING ABILITY**					
IC212140×IC532889	-0.36	-2.18***	-0.24***	-5.01***	-1.92 ***	0.23
IC212140×IC82322	6.62***	3.70***	-0.34***	-6.78***	10.52 ***	-24.91***
IC212140×IC78751	2.83***	9.81***	-0.32***	-6.89***	10.51 ***	4.93***
IC212140×IC138866	-0.85*	-1.37***	-0.38***	-6.78***	-9.48 ***	25.23***
IC212140×IC78737	-0.84*	2.76***	1.02***	6.60***	-0.62	6.21***
IC212140×IC55681	4.50***	0.54	-0.07	0.12	4.19 ***	-11.49***
IC212140×IC78801	-0.67	3.23***	0.00	4.79***	3.62 ***	-1.52**
IC212140×IC75310	-2.42***	0.51	0.18***	10.37 ***	-0.33	1.54**
IC212140×IC75310	-5.61***	2.12***	-0.14**	6.37 ***	-1.60 ***	9.54***
IC532889×IC82322	-2.57***	-2.90	-1.75***	-6.73***	0.83	-15.46***
IC532889×IC78751	4.23***	7.87	-0.69***	7.82***	-0.85 *	25.37***
IC532889×IC138866	-2.12***	-0.32	0.24***	4.93***	-3.43 ***	9.34***
IC532889×IC78737	5.63***	2.81***	1.08***	0.32	11.59 ****	-23.35***

IC532889×IC55681	-5.43***	-0.07	-0.88***	0.85 *	3.69 ***	-12.38***
IC532889×IC78801	-2.10***	-3.37***	-0.96***	0.18	-4.62 ***	3.59***
IC532889×IC75310	-8.02***	-0.90*	-0.48***	4.43 ***	0.74	-0.02
IC532889×IC75310	2.30***	-2.48***	0.91***	-2.89 ***	5.12 ***	-19.35***
IC82322×IC78751	6.21***	8.76***	0.77***	10.37***	-2.17 ***	34.90***
IC82322×IC138866	-5.13***	0.90*	-1.26***	8.15***	-1.65 ***	6.54***
IC82322×IC78737	2.27***	-11.29***	-0.08	6.87***	-7.32 ***	-2.82***
IC82322×IC55681	2.22***	2.48***	0.71***	1.07 *	0.77	4.15***
IC82322×IC78801	-0.95*	3.17***	0.367 ***	-3.92***	-1.38 **	14.79***
IC82322×IC75310	-2.03***	6.12***	2.51***	0.65	1.37 **	12.51***
IC82322×IC75310	-7.72**	-6.26***	1.04***	-0.01	-4.36 ***	-2.49***
IC78751×IC138866	-6.93***	-10.32***	-0.89***	0.04	-2.23 ***	-21.96***
IC78751×IC78737	-3.86***	-12.84***	0.01	3.10***	-3.48 ***	-33.32***
IC78751×IC55681	-11.58***	-5.73***	0.37***	1.62***	3.16 ***	-25.68***
IC78751×IC78801	-10.25***	-10.04***	0.22***	-3.03***	-1.19 **	-25.38***
IC78751×IC75310	-3.83***	-11.09***	0.17***	-0.78	-2.05 ***	-27.99***
IC78751×IC75310	-6.98***	-8.82***	1.47***	-1.45**	-4.97 ***	-14.99***
IC138866×IC78737	2.13***	0.29	0.51***	7.21***	2.56 ***	-8.68***
IC138866×IC55681	5.41***	2.06***	0.27***	4.07***	2.84 ***	-4.38***
IC138866×IC78801	7.24***	2.43***	-0.63***	-3.92***	1.41 ***	2.26***
IC138866×IC75310	0.82*	1.37***	-0.25***	-6.01***	1.83 ***	-1.68***
IC138866×IC75310	1.34**	-0.01	0.87***	-0.01	0.44	-1.35**
IC78737×IC55681	-0.18	4.87***	0.25***	-1.87***	0.20	13.26***
IC78737×IC78801	-6.99***	1.90***	-0.12*	-5.53***	-3.24***	17.57***
IC78737×IC75310	-2.44***	4.51***	0.22***	-8.28***	-0.59	15.29***
IC78737×IC75310	-2.79***	5.45***	-1.38***	-2.95***	0.73	13.29***
IC55681×IC78801	5.59***	-3.98***	0.10*	-1.67***	-4.40***	1.54**
IC55681×IC75310	6.17***	-2.37***	0.18***	-2.09***	-6.72***	18.93***
IC55681×IC75310	9.15***	0.23	0.65***	-2.76***	-3.84***	14.93***
IC78801×IC75310	6.67***	0.31	0.30**	4.24***	0.79	-2.10***
IC78801×IC75310	5.98***	2.92***	-0.39***	4.24***	2.68***	-0.43
IC75310×IC75310	3.24***	-2.12***	-1.18***	1.15**	-1.87***	-0.38

*Significance P ≤0.05; **Significance P ≤0.01; ***Significance P ≤0.001

4.3.11 Biological yield

Parents and crosses exhibiting notable positive GCA and SCA impacts are preferable for biological yield. In F1 generation, parental lines IC82322, IC78737, IC55681, IC78801, IC75310, and IC75310 exhibited strong favourable GCA effects, and were regarded as an excellent overall cross breeders for biological yield. Additional comparison across the settings revealed that the parental lines IC212140, IC532889, IC78751, and IC138866 showed unfavourable GCA effect and indicating their inferior general combining ability for biological yield (Table 4.3.2 and 4.3.4).

Five crosses in Punjab and 21 crosses in Meerut exhibited substantial beneficial SCA effects. The crosses, IC212140×IC78751, IC212140×IC138866, IC212140×IC78737, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC78801, IC82322×IC78751, IC82322×IC138866, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, and IC55681×IC75310 in Meerut and the crosses IC212140×IC78751, IC212140×IC138866, IC212140×IC78737, IC212140×IC75310, IC212140×IC75310 in Punjab exhibited favourable SCA effects consistently, thus, these are deemed desirable crosses.

4.4 Heterosis in F1 and Inbreeding depression in F2 generation

The heterosis of F1 hybrids was determined by calculating the percentage change (+) or decrease (-) with regard to the superior parent (Heterobeltiosis) or the average of the parents (heterosis). Additionally, for every trait in specific situations, the percentage decline in F2 hybrids compared to F1 hybrids (inbreeding depression) was computed for 45 F_1s in drought stress conditions.

4.4.1 Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation in Punjab

The outputs of Mid-parent heterosis (H), Better parent heterosis (HB) and Inbreeding depression (IB) for 10 parents along with 45 F_1s for eleven attributes are given in Table 4.4.1 ,4.4.2, 4.4.3, and 4.4.4.

4.4.1.1 Days to 75% flowering

The range for days to seventy five percent flowering varied from -9.96** (IC55681×IC75310) to 14.72** (IC212140×IC78737) for heterosis. Ten genotypes *viz.* IC212140×IC78737, IC532889×IC78751, IC82322×IC78751, IC82322×IC78737, IC78751×IC78737, IC138866×IC78737, IC138866×IC75310, IC138866×IC75310, IC55681×IC75310, IC55681×IC75310 exhibited notable negative and desirable mid-parent heterosis. Twenty-one hybrids *viz.* IC212140×IC78737, IC212140×IC55681,

IC212140×IC78801, IC212140×IC75310, IC532889×IC78751, IC532889×IC78801, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC75310, IC78751×IC78737, IC78751×IC78801, IC138866×IC78737, IC138866×IC75310, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310 were found negative significant and desirable for heterobeltiosis (Table 4.4.1).

For inbreeding depression, a positive magnitude is required for days to 75% flowering. Out of 45 crosses, seventeen showed a positive response (Table 4.4.1).

4.4.1.2 Days to Maturity

The range for days to maturity varied from -2.64 to 1.51. thirteen crosses IC212140×IC532889, IC212140×IC75310, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC75310, IC78751×IC78737, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC55681×IC75310, IC75310×IC75310 showed the negative significant magnitude for heterosis. While thirty-two crosses showed the positive and undesirable magnitude for heterosis. Eighteen hybrids viz. IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC75310, IC532889×IC82322, IC532889×IC78751, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC75310, IC78751×IC78737, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC78737×IC75310, IC55681×IC75310, IC75310×IC75310 possessed negative significant heterobeltiosis (Table 4.4.1).

4.3.1.3 Plant height

The crosses with negative substantial heterosis and heterobeltoisis are desirable for plant height.

In the F1 generation, 22 hybrids exhibited highly favorable heterosis. The crosses IC212140×IC82322, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC532889×IC82322, IC532889×IC138866, IC532889×IC78737, IC532889×IC55681, IC532889×IC78801, IC532889×IC75310, IC532889×IC75310, IC82322×IC78801, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC78737, IC138866×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC55681×IC78801, IC55681×IC75310 showed negative significant heterosis, hence considered as desirable crosses.

Thirty hybrids viz. IC212140×IC82322, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC532889×IC82322, IC532889×IC138866, IC532889×IC78737,

IC532889×IC55681, IC532889×IC78801, IC532889×IC75310, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC78737, IC138866×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, IC78801×IC75310 showed the negative significant heterobetiosis (Table 4.4.1).

Table 4.4.1 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Days to 75% flowering, Days to Maturity and Plant Height in Punjab

Trait	Days to 75% flowering			Days to maturity			Plant height		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	5.88 **	5.15 **	-1.31	-1.26 *	-1.26 *	0.00	5.57 **	-0.05	0.00
IC212140×IC82322	1.93 **	1.05	-0.69	-0.75	-1.25 *	0.00	-22.94 **	-28.66**	0.00
IC212140×IC78751	-0.70	-0.70	0.70	-0.75	-1.25 *	0.00	22.10 **	18.48 **	0.00
IC212140×IC138866	14.72 **	5.92**	-0.99	-0.63	-0.76	0.00	15.27 **	13.87 **	0.00
IC212140×IC78737	-1.73 **	-2.41 **	-1.06	-0.25	-0.25	0.00	-12.69 **	-16.58**	0.00
IC212140×IC55681	8.32 **	-2.44 **	-1.07	1.51 **	1.25 *	0.00	13.05 **	12.43 **	0.00
IC212140×IC78801	9.94 **	-1.74 **	-1.06	0.38	0.25	0.00	-5.07 **	-12.07**	0.00
IC212140×IC75310	1.08	-2.44 **	-0.71	0.88	0.50	0.00	-0.58	-3.25 **	0.00
IC212140×IC75310	3.04 **	0.35	-0.69	-1.13 *	-1.74 **	0.00	14.18 **	13.39 **	0.00
IC532889×IC82322	0.87	-0.69	0.69	-0.75	-1.25 *	0.00	-8.07 **	-19.07 **	0.00
IC532889×IC78751	-2.42 **	-3.09**	0.35	-0.75	-1.25 *	0.00	23.14 **	13.32 **	0.00
IC532889×IC138866	8.24 **	-0.69	-0.69	1.13 *	1.01	0.00	-30.88 **	-35.32 **	0.00
IC532889×IC78737	-0.34	-0.34	-1.03	0.76	0.76	0.00	-16.76 **	-24.50 **	0.00
IC532889×IC55681	10.94	-0.69	-0.35	-1.01 *	-1.25 *	0.00	-11.03	-16.20 **	0.00

	**						**		
IC532889×IC78801	7.16 **	-4.81**	-1.08	0.13	0.00	0.00	-26.13 **	-34.93 **	0.00
IC532889×IC75310	0.00	-4.12**	-1.08	0.88	0.50	0.00	-23.27 **	-29.20 **	0.00
IC532889×IC75310	4.09 **	0.69	-0.34	-1.13 *	-1.74 **	0.00	-42.90 **	-46.30 **	0.00
IC82322×IC78751	-2.28 **	-3.14**	-0.72	-2.49 **	-2.49 **	0.00	2.31 **	-2.53 **	0.00
IC82322×IC138866	7.05 **	-0.35	-0.71	-1.13 *	-1.75 **	0.00	15.59 **	8.24 **	0.00
IC82322×IC78737	-2.62 **	-4.12**	0.72	0.75	0.25	0.00	0.83 *	-2.46 **	0.00
IC82322×IC55681	10.16 **	0.00	0.35	-0.5	-0.75	0.13	1.94 **	-5.14 **	0.60
IC82322×IC78801	9.84 **	-1.06	0.07	-0.63	-1.00	0.23	-3.02 **	-3.08 **	-0.58
IC82322×IC75310	0.55	-2.13**	-0.11	-1.87 **	-2.00 **	-0.64	3.59 **	-1.60 **	0.85
IC82322×IC75310	1.44 *	-0.35	-0.32	-0.87	-1.00	0.35	0.81 *	-6.08 **	0.31
IC78751×IC138866	9.06 **	0.70	0.48	0.38	-0.25	0.33	5.37 **	3.48 **	0.21
IC78751×IC78737	-2.08 **	-2.75**	-0.07	-1.00 *	-1.50 **	-0.48	17.65 **	15.79 **	0.16
IC78751×IC55681	10.64 **	-0.35	0.03	-0.25	-0.50	0.15	-3.06 **	-5.43 **	0.32
IC78751×IC78801	8.77 **	-2.79**	0.29	-0.63	-1.00	0.30	-4.39 **	-8.87 **	0.05
IC78751×IC75310	4.69 **	1.05	0.28	-1.37 **	-1.50 **	-0.05	-12.24 **	-12.50 **	0.06
IC78751×IC75310	4.47 **	1.74**	-0.34	-0.12	-0.25	-0.75	20.47 **	17.69 **	0.69
IC138866×IC78737	-6.74 **	-14.43**	0.00	-1.89 **	-2.02 **	0.00	-0.93 *	-4.21 **	0.00
IC138866×IC55681	4.86 **	2.06**	0.00	-2.64 **	-3.01 **	0.00	7.26 **	6.54 **	0.00
IC138866×IC78801	5.33 **	1.65*	0.00	-0.25	-0.50	0.00	-21.53 **	-26.48 **	0.00
IC138866×IC75310	-2.35 **	-6.74**	0.00	1.01 *	0.50	0.00	-5.63 **	-7.05 **	0.00
IC138866×IC75310	-5.24 **	-10.29**	-2.87	-0.25	-1.00	-1.26	-0.99 *	-1.52 **	-0.57

IC78737×IC55681	10.94 **	-0.69	1.38	-0.75	-1.00	-0.25	-13.34 **	-16.76 **	-1.26
IC78737×IC78801	9.48 **	-2.75**	-1.41	0.63	0.50	-1.00	-15.80 **	-18.50 **	-2.42
IC78737×IC75310	1.79 **	-2.41**	-1.06	-0.88	-1.25 *	-0.51	0.03	-1.84 **	-0.80
IC78737×IC75310	1.60 **	-1.72**	-0.35	0.13	-0.50	-2.00	9.44 **	5.26 **	-0.75
IC55681×IC78801	1.32	0.43	-0.87	-0.13	-0.25	-1.01	-4.76 **	-11.33 **	-0.56
IC55681×IC75310	-7.04 **	-13.48**	0.87	0.38	0.25	-1.00	5.98 **	3.69 **	0.00
IC55681×IC75310	-9.96 **	-16.91**	-1.33	-1.87 **	-2.24 **	-1.02	-3.00 **	-3.13 **	-1.47
IC78801×IC75310	5.88 **	-2.25**	-0.77	1.25 *	1.00	-0.62	5.21 **	0.00	-0.99
IC78801×IC75310	2.01 **	-6.62**	0.00	0.25	-0.25	-0.50	-0.4	-7.14 **	-1.06
IC75310×IC75310	2.04 **	1.10	-0.73	-1.25 *	-1.49 **	-1.26	14.40 **	12.08 **	-0.49

*Significance P ≤0.05; **Significance P ≤0.01

4.4.1.4 No. of spikelets /spike

No. of spikelets /spike is a beneficial parameter for yield enhancement, correlated with favorable heterosis effects. Consequently, the crossings exhibiting significant positive heterosis are preferred. In F1 generation, 19 crosses exhibited positive significant Heterosis. The crossings IC212140×IC138866, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC138866, IC532889×IC78737, IC82322×IC138866, IC82322×IC78737, IC82322×IC78801, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×9, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC78801×IC75310 for heterosis whereas, twelve hybrids viz. IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC532889×IC138866, IC82322×IC78801, IC82322×IC75310,IC78751×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC78801×IC75310 for heterobeltoisis, exhibited positive significant heterosis. Therefore, are deemed desirable for this trait (Table 4.4.2).

4.4.1.5 Number of grains per spike

An increased grain count per spike is advantageous for enhanced grain yield and coincides with positive heterosis and heterobeltiosis. Thus, it is preferable to have crosses that have major positive impacts. There was positive substantial heterosis in seventeen hybrids from the F1 generation.

The crossings IC212140×IC532889, IC212140×IC82322, IC212140×IC138866, IC212140×IC78737, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC82322×IC138866, IC82322×IC78801, IC82322×IC75310, IC138866×IC78737, IC138866×IC75310, IC138866×IC75310, IC78737×IC78801, IC55681×IC75310, IC55681×IC75310, and IC78801×IC75310 exhibited considerable positive heterosis and are therefore regarded as favorable crosses. Twenty-two crossings demonstrated non-significant heterosis, hence deemed unsuitable for this feature. Eleven crosses viz. IC212140×IC532889, IC212140×IC82322, IC532889×IC78751, IC532889×IC138866, IC82322×IC78751, IC82322×IC78801, IC138866×IC75310, IC138866×IC75310, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310 showed the desirable positive heterobeltiosis (Table 4.4.2).

4.4.1.6 1000-grain weight

It is desirable for this feature to have both positive heterosis and heterobeltiosis. Crosses that have a significant magnitude that is positive are therefore preferred. In the F1 generation, fifteen showed a positive significant magnitude.

The crosses IC212140×IC82322, IC212140×IC55681, IC212140×IC78801, IC532889×IC78737, IC82322×IC55681, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 were deemed desirable crosses because they had positive substantial heterosis. Eleven crosses viz. IC212140×IC82322, IC212140×IC55681, IC82322×IC55681, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310 exhibited the positive heterobeltiosis (Table 4.4.2).

Table 4.4.2 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for No. of spikelets per spike, No. of grains per spike and 1000 seeds weight in Punjab

Trait	No. of spikelets per spike			No. grains per spike			1000 seeds weight		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	-5.36	-10.17**	0.00	9.60**	2.65**	0.00	-3.65 **	-18.77**	-1.52
IC212140×IC82322	-0.92	-3.57	0.00	4.39 **	2.02 *	0.00	18.91 **	14.43 **	-1.45
IC212140×IC78751	-6.09 *	-12.90**	0.00	-5.82 **	-10.05 **	0.00	-13.04	-19.23**	-1.90

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IC212140×IC138866	7.14 *	1.69	0.00	5.62 **	-0.53	0.00	1.00	-8.70 **	-0.79
IC212140×IC78737	10.48 **	9.43 **	0.00	3.85 **	0.00	0.00	-4.53 **	-11.01**	-0.87
IC212140×IC55681	2.80	1.85	0.00	-31.56 **	-31.75 **	0.00	25.17 **	23.77 **	-0.72
IC212140×IC78801	10.28 **	9.26 **	0.00	-4.81 **	-5.82 **	0.00	3.89 **	-4.51 **	-1.57
IC212140×IC75310	6.19 *	0.00	0.00	6.63 **	-2.12 *	0.00	-5.20 **	-11.63**	0.00
IC212140×IC75310	10.09 **	7.14 *	0.00	-15.51 **	-16.40 **	0.00	-11.97 **	-19.63**	-0.92
IC532889×IC82322	-9.57 **	-11.86**	0.00	-3.03 **	-11.11 **	0.00	-11.55 **	-22.95**	-1.60
IC532889×IC78751	-10.74 **	-12.90**	0.00	15.13 **	12.79 **	0.00	-11.11 **	-20.00**	0.00
IC532889×IC138866	10.17 **	10.17 **	0.00	42.77 **	41.92 **	0.00	-7.49 **	-14.46**	0.00
IC532889×IC78737	6.31 *	0.00	0.00	-2.94 **	-5.71 **	0.00	2.92 **	-7.69 **	-2.00
IC532889×IC55681	-7.96 **	-11.86**	0.00	-13.31 **	-18.62 **	0.00	-8.66 **	-23.69**	-1.61
IC532889×IC78801	2.65	-1.69	0.00	-9.71 **	-14.59 **	0.00	-5.58 **	-14.15**	-0.72
IC532889×IC75310	-12.61 **	-13.33**	0.00	-0.93	-3.03 **	0.00	-24.53 **	-32.31**	0.00
IC532889×IC75310	-0.87	-3.39	0.00	-13.14 **	-17.84 **	0.00	0.17	-8.31 **	0.00
IC82322×IC78751	-8.47 **	-12.90**	0.00	-1.62 *	-8.08 **	0.00	-3.43 **	-6.92 **	0.00
IC82322×IC138866	6.09 *	3.39	0.00	24.38 **	14.65 **	0.00	-11.06 **	-16.67**	0.00
IC82322×IC78737	7.41 *	3.57	0.00	-14.21 **	-19.19 **	0.63	0.96	-2.33	0.00
IC82322×IC55681	-1.82	-3.57	-0.19	-18.13 **	-20.20 **	-1.90	15.85 **	10.28 **	0.00
IC82322×IC78801	9.09 **	7.14 *	-0.17	12.27 **	8.59 **	-0.42	-2.21	-6.77 **	0.00
IC82322×IC75310	5.17	1.67	1.15	6.18 **	-4.55 **	1.27	-6.25 **	-9.30 **	0.00
IC82322×IC75310	7.14 *	7.14 *	-3.83	-14.36	-17.17 **	0.18	-18.62	-22.96 **	0.00

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IC78751×IC138866	-14.05 **	-16.13 **	-3.46	-19.76 **	-20.93 **	0.44	-32.09 **	-34.06 **	0.00
IC78751×IC78737	1.75	-6.45 *	-1.21	-36.02 **	-36.57 **	1.80	-31.27 **	-31.54 **	0.00
IC78751×IC55681	10.34 **	3.23	2.03	-45.00 **	-47.34 **	0.61	-38.08 **	-43.08 **	0.00
IC78751×IC78801	13.79 **	6.45 *	0.15	-37.25 **	-39.46 **	2.14	-38.02 **	-38.72 **	0.00
IC78751×IC75310	-4.92	-6.45 *	-2.24	-40.00 **	-42.44 **	0.10	-28.19 **	-28.46 **	0.00
IC78751×IC75310	8.47 **	3.23	-4.69	-46.22 **	-48.11 **	-2.08	-33.13 **	-34.37 **	0.00
IC138866×IC78737	0.90	-5.08	0.00	1.75 *	-0.57	0.00	1.87	-1.45	0.00
IC138866×IC55681	-2.65	-6.78 *	0.00	-4.79 **	-10.11 **	-1.18	23.08 **	10.14 **	0.00
IC138866×IC78801	-2.65	-6.78 *	0.00	-18.18 **	-22.16 **	-0.69	19.56 **	17.39 **	0.00
IC138866×IC75310	7.56 **	6.67 *	0.00	40.31 **	36.53 **	-0.88	1.87	-1.45	0.00
IC138866×IC75310	21.74 **	18.64 **	-1.43	22.16 **	16.22 **	-1.86	4.47 **	3.33 **	-2.45
IC78737×IC55681	16.98 **	14.81 **	-3.23	1.38	-2.13 *	-2.17	3.36 **	-4.65 **	-4.88
IC78737×IC78801	-15.09 **	-16.67 **	-4.44	3.33 **	0.54	-2.15	-17.48 **	-18.72 **	-1.85
IC78737×IC75310	21.43 **	13.33 **	-1.47	-17.72 **	-21.71 **	-1.46	-10.85 **	-10.85 **	0.00
IC78737×IC75310	-1.85	-5.36	-1.89	-17.78 **	-20.00 **	-1.35	-10.61 **	-12.59 **	-3.39
IC55681×IC78801	0.00	0.00	-3.70	-5.09 **	-5.85 **	-1.69	26.45 **	15.04 **	-3.27
IC55681×IC75310	-3.51	-8.33 **	-1.82	12.14 **	3.19 **	-1.55	24.37 **	14.73 **	-0.68
IC55681×IC75310	-1.82	-3.57	3.70	5.09 **	4.26 **	-1.53	31.97 **	19.26 **	-2.48
IC78801×IC75310	14.04 **	8.33 **	-6.15	17.20 **	8.65 **	-1.00	16.79 **	15.04 **	-2.61
IC78801×IC75310	5.45	3.57	-5.17	-14.59 **	-14.59 **	-3.16	15.67 **	14.81 **	-3.23

IC75310×IC75310	-5.17	-8.33 **	5.45	-18.37 **	-24.32 **	-2.14	4.55 **	2.22	-2.17

*Significance P ≤0.05; **Significance P ≤0.01

4.3.1.7 Grain yield per plant

A positive magnitude indicates that a higher grain yield is desirable. Hence, crosses with a positive significant magnitude are desirable. In the F1 generation, seventeen crosses showed positive significant heterosis. The crosses IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC138866, IC212140×IC78737, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78737, IC82322×IC78751, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC78737×IC55681, IC78737×IC75310, IC78737×IC75310 were deemed desirable crosses because they had positive substantial heterosis. Fifteen hybrids viz. IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC75310, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC78737×IC55681, IC78737×IC75310, IC78737×IC75310 exhibited the desirable positive heterobeltiosis (Table 4.4.7).

4.4.1.8 Spike length

Extended spike length is seen as advantageous for increased grain yield and correlates with a positive magnitude. Therefore, crosses exhibiting positive substantial effects are preferable.

In the F1 generation, twenty-eight crosses showed positive significant heterosis. The crosses IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC78737, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC138866, IC78751×IC78737, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, and IC78801×IC75310 exhibited significant positive heterosis, while the crosses IC212140×IC78737, IC212140×IC75310, IC532889×IC75310, IC82322×IC78751, IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC78737×IC55681, IC78737×IC75310, IC55681×IC75310, and IC55681×IC75310 demonstrated significant positive heterobeltiosis, thus deemed as favorable crosses (Table 4.4.3).

4.4.1.9 Number of tillers per plant

A greater number of tillers per plant is deemed advantageous and correlates with a positive magnitude. Therefore, parents and crosses exhibiting favourable substantial effects are preferred. In the F1 generation, twenty-six hybrids exhibited considerable positive heterosis. The crossings IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC78737, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC138866, IC78751×IC78737, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC138866×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crosses.

Nineteen crosses, namely IC212140×IC78737, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC75310, IC82322×IC75310, IC78751×IC138866, IC78751×IC78737, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC78737×IC55681, IC78801×IC75310, and IC75310×IC75310, exhibited considerable positive heterobeltiosis (Table 4.4.3).

Table 4.4.3. Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Grain yield per plant, Spike length and No. of tillers per plant in Punjab

Trait	Grain yield per plant			Spike length			No. of tillers per plant		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	8.65 **	7.62 **	-2.65	-2.36 **	-4.92 **	0.34	-20.39 **	-35.94**	0.00
IC212140×IC82322	26.32 **	17.07 **	1.39	3.53 **	-6.91 **	-2.97	-23.91 **	-33.96 **	-8.57
IC212140×IC78751	17.75 **	7.94 **	-1.47	2.11 **	0.35	-0.34	-22.73 **	-30.61 **	-5.88
IC212140×IC138866	5.53 **	-4.62 **	-2.42	-5.13 **	-11.64 **	-0.17	-26.00 **	-39.34 **	-5.41
IC212140×IC78737	19.48 **	9.52 **	-0.72	19.08 **	6.92 **	-3.24	68.00 **	61.54 **	-6.35
IC212140×IC55681	14.16 **	9.65 **	-2.40	6.16 **	1.38	0.00	5.56	-2.56	-5.26

IC212140×IC78801	19.48 **	9.52 **	0.72	-0.34	-2.64 **	3.39	26.00 **	3.28	-7.94
IC212140×IC75310	14.67 **	7.50 **	-0.78	9.06 **	6.23 **	-6.51	74.47 **	49.09 **	-1.22
IC212140×IC75310	13.04 **	4.00 **	-1.54	5.95 **	1.73 *	6.80	51.16 **	38.30 **	-4.62
IC532889×IC82322	-4.42 **	-12.20 **	-1.85	-13.34**	-20.17 **	3.46	-16.24**	-23.44 **	-8.16
IC532889×IC78751	-0.44	-9.52 **	-1.75	-6.51 **	-10.49 **	-1.47	62.83 **	43.75 **	-5.43
IC532889×IC138866	-3.86 **	-13.85 **	-0.89	-3.44 **	-7.76 **	-4.21	39.20 **	35.94 **	-1.15
IC532889×IC78737	5.68 **	-3.97 **	-1.65	14.02 **	0.00	-3.28	18.00 **	-7.81 **	-6.78
IC532889×IC55681	-1.38	-6.14 **	-0.93	-7.39 **	-13.77 **	0.00	11.34 **	-15.63 **	-1.85
IC532889×IC78801	-10.92 **	-19.05 **	-0.98	-14.47 **	-14.75 **	-3.85	0.8	-1.56	-6.35
IC532889×IC75310	1.35	-5.83 **	-0.88	-2.94 **	-7.87 **	0.00	32.77 **	23.44 **	-1.27
IC532889×IC75310	-12.28 **	-20.00 **	-2.00	12.08 **	4.92 **	-3.13	-6.31 **	-18.75 **	-7.69
IC82322×IC78751	4.42 **	3.17 *	-1.54	14.51 **	1.38 *	0.00	92.16 **	84.91 **	-3.06
IC82322×IC138866	1.98	-0.77	-0.78	-9.90 **	-13.26 **	-3.18	64.91 **	54.10 **	-2.13
IC82322×IC78737	-26.10 **	-26.98 **	-3.26	8.11 **	-11.60 **	-3.13	73.03 **	45.28 **	-1.30
IC82322×IC55681	8.02 **	4.07 **	-3.13	15.52 **	-0.28	0.00	23.26 **	0.00	-1.89
IC82322×IC78801	8.43 **	7.14 **	-2.22	5.26 **	-3.31 **	-5.71	-14.04 **	-19.67 **	-2.04
IC82322×IC75310	16.87 **	15.45 **	0.70	32.39 **	16.30 **	-2.38	20.37 **	18.18 **	-3.08
IC82322×IC75310	-17.74 **	-18.40 **	-3.92	19.11 **	3.31 **	-2.67	16.00 **	9.43 **	-1.72
IC78751×IC138866	-46.09 **	-46.92 **	-5.80	-9.77 **	-17.31 **	-2.17	27.27 **	14.75 **	-1.43
IC78751×IC78737	-51.59 **	-51.59 **	-4.92	8.06 **	-1.43	-2.55	50.59 **	30.61 **	-1.56
IC78751×IC55681	-35.83 **	-38.89 **	-3.90	11.81 **	8.60 **	-3.30	31.71 **	10.20 **	-1.85
IC78751×IC78801	-43.65 **	-43.65 **	-5.63	2.41 **	-1.65 *	-6.71	-7.27 **	-16.39 **	-1.96
IC78751×IC75310	-48.78	-50.00 **	-6.35	9.58 **	8.60 **	-9.90	15.38 **	9.09 **	-3.33

	**								
IC78751×IC75310	-45.82 **	-46.03 **	-1.47	24.40 **	21.51 **	-5.90	12.50 **	10.20 **	-1.85
IC138866×IC78737	-3.12 **	-4.62 **	0.00	5.49 **	-11.04 **	0.00	67.01 **	32.79 **	0.00
IC138866×IC55681	0.00	-6.15 **	0.00	3.01 **	-8.06 **	0.00	38.30 **	6.56 **	0.00
IC138866×IC78801	0.78	-0.77	0.00	-12.23 **	-16.42 **	0.00	-14.75 **	-14.75 **	0.00
IC138866×IC75310	-0.80	-4.62 **	0.00	-2.13 **	-11.04 **	0.00	-15.52 **	-19.67 **	0.00
IC138866×IC75310	-8.24 **	-10.00 **	-3.42	9.48 **	-1.79 **	-18.24	14.81 **	1.64	-6.45
IC78737×IC55681	10.00 **	4.76 **	-0.76	12.78 **	5.70 **	-3.60	-4.35	-8.33	-6.06
IC78737×IC78801	1.59	1.59	-0.78	-0.19	-12.21 **	-3.76	-34.02 **	-47.54 **	-3.13
IC78737×IC75310	8.94 **	6.35 **	-2.99	12.30 **	3.28 **	0.00	-38.46 **	-49.09 **	-3.57
IC78737×IC75310	6.77 **	6.35 **	-2.24	-6.45 **	-12.78 **	-8.62	-6.02	-17.02 **	-5.13
IC55681×IC78801	-13.33 **	-17.46 **	-2.88	2.47 **	-4.29 **	6.90	-21.28 **	-39.34 **	-2.70
IC55681×IC75310	-8.55 **	-10.83 **	-1.87	11.36 **	9.12 **	-3.34	-9.09 **	-27.27 **	-2.50
IC55681×IC75310	-6.28 **	-10.40 **	-2.68	17.20 **	16.54 **	-9.68	-15.00 **	-27.66 **	-11.76
IC78801×IC75310	-2.44 *	-4.76 **	-0.83	4.68 **	-0.33	-6.62	20.69 **	14.75 **	-2.86
IC78801×IC75310	-1.20	-1.59	-4.84	-2.28 **	-8.25 **	-2.16	18.52 **	4.92	-6.25
IC75310×IC75310	-13.47 **	-15.20 **	-3.77	-3.33 **	-4.74 **	-3.45	15.69 **	7.27 **	-1.69

*Significance P ≤0.05; **Significance P ≤0.01

4.4.1.10 Harvest index

The advantageous heterosis and heterobeltiosis are favorable for this characteristic. Therefore, crosses with a substantial positive magnitude are preferred.

In the F1 generation, fourteen crosses exhibited considerable positive heterosis. The crosses IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC55681, IC212140×IC78801, IC532889×IC82322, IC532889×IC78751, IC532889×IC78737, IC532889×IC55681, IC532889×IC75310, IC532889×IC75310, and

IC78751×IC55681 demonstrated significant positive heterosis, thus classified as desirable crosses. Conversely, nine crosses, namely IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC532889×IC138866, IC532889×IC78737, and IC532889×IC75310, exhibited significant positive heterobeltiosis (Table 4.4.4).

Table 4.4.4 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Harvesting Index and Biological Yield in Punjab

Trait	Harvesting Index			Biological Yield		
Cross	H	HB	ID	H	HB	ID
IC212140×IC532889	13.84 **	4.58 **	-2.30	-5.21**	-12.15 **	-0.35
IC212140×IC82322	41.24 **	23.22 **	2.65	-13.48 **	-29.23 **	-1.31
IC212140×IC78751	36.34 **	35.49 **	-1.12	-13.67**	-21.32 **	-0.38
IC212140×IC138866	-18.85 **	-23.79**	-1.92	30.42 **	25.17 **	-0.54
IC212140×IC78737	9.81 **	0.04	0.09	6.82 **	-10.00 **	-0.83
IC212140×IC55681	23.18 **	12.49 **	-1.34	-8.52 **	-19.44 **	-1.03
IC212140×IC78801	14.98 **	13.08 **	2.59	4.05 **	-3.14 **	-1.95
IC212140×IC75310	5.69 **	5.55 **	0.17	8.50 **	1.59 **	-0.94
IC212140×IC75310	1.11	-0.21	-0.06	11.66 **	1.49 **	-1.47
IC532889×IC82322	9.30 **	3.25	-1.22	-13.30 **	-24.36 **	-0.61
IC532889×IC78751	3.19 *	-4.65 **	-0.17	-3.36 **	-5.11 **	-1.58
IC532889×IC138866	-6.96 **	-19.26 **	0.67	2.75 **	-0.93	-1.57
IC532889×IC78737	43.63 **	42.31 **	-0.53	-26.49 **	-33.75 **	-1.13
IC532889×IC55681	19.90 **	19.11 **	1.22	-17.77 **	-22.22 **	-2.14
IC532889×IC78801	-9.39 **	-18.01 **	0.60	-1.72 **	-2.18 **	-1.59
IC532889×IC75310	5.05 **	-3.38 *	0.73	-3.62 **	-4.67 **	-1.63
IC532889×IC75310	17.64 **	9.40 **	0.48	-25.30 **	-26.87 **	-2.45
IC82322×IC78751	-11.79 **	-22.63 **	-1.09	16.23 **	3.02 **	-0.45
IC82322×IC138866	-12.58 **	-27.70 **	-0.05	12.21 **	-5.10 **	-0.73
IC82322×IC78737	-27.71 **	-31.11 **	-2.06	2.05 **	-1.62 **	-1.18
IC82322×IC55681	-0.87	-5.77 **	-2.62	8.47 **	-0.46	-0.47
IC82322×IC78801	-11.57 **	-23.94 **	-1.99	19.63 **	3.94 **	-0.22
IC82322×IC75310	-3.96 **	-16.13 **	0.69	18.93 **	2.78 **	0.00
IC82322×IC75310	-21.57 **	-30.80 **	-2.40	3.13 **	-8.35 **	-1.52
IC78751×IC138866	-11.34 **	-17.22 **	-2.13	-39.46 **	-42.64 **	-3.66
IC78751×IC78737	-12.90 **	-20.20 **	-6.26	-44.88 **	-49.50 **	0.99
IC78751×IC55681	7.54 **	-1.23	-3.17	-40.55 **	-42.78 **	-0.73
IC78751×IC78801	-6.00 **	-8.12 **	-2.87	-40.09 **	-41.44 **	-2.82

IC78751×IC75310	-12.35 **	-12.79 **	-2.63	-41.58 **	-43.24 **	-3.70
IC78751×IC75310	-19.57 **	-20.13 **	-0.10	-32.63 **	-32.84 **	-1.33
IC138866×IC78737	1.58	-12.54 **	0.30	-6.88 **	-18.75 **	-0.31
IC138866×IC55681	1.27	-12.61 **	0.62	-2.74 **	-11.11 **	-0.62
IC138866×IC78801	-4.92 **	-9.28 **	0.63	5.84 **	2.52 **	-0.61
IC138866×IC75310	-4.71 **	-10.61 **	0.00	3.92 **	1.27 *	0.00
IC138866×IC75310	-8.52 **	-15.13 **	-3.10	-0.16	-5.67 **	-0.32
IC78737×IC55681	0.22	-0.04	-1.50	9.74 **	4.25 **	0.72
IC78737×IC78801	-13.69 **	-22.54 **	-0.31	16.16 **	4.25 **	-0.48
IC78737×IC75310	-6.71 **	-14.91 **	-2.99	15.41 **	3.00 **	0.00
IC78737×IC75310	-3.37 *	-10.90 **	-1.98	9.66 **	0.75	-0.25
IC55681×IC78801	-16.88 **	-25.23 **	-1.47	3.54 **	-2.50 **	-1.42
IC55681×IC75310	-24.57 **	-31.03 **	-0.63	20.47 **	12.78 **	-1.23
IC55681×IC75310	-16.73 **	-23.04 **	-1.63	12.23 **	8.33 **	-1.03
IC78801×IC75310	-6.27 **	-7.93 **	-0.87	4.11 **	3.46 **	0.00
IC78801×IC75310	-2.62 *	-5.45 **	-4.60	1.38 **	-1.19 *	-0.30
IC75310×IC75310	-16.21 **	-17.20 **	-1.92	3.24 **	0.00	-1.79

*Significance P ≤0.05; **Significance P ≤0.01

4.4.1.11 Biological yield

The advantageous heterosis and heterobeltiosis are favourable for this feature. Therefore, crosses exhibiting a substantial positive magnitude are preferable. Twenty-five crosses in F1 exhibited considerable positive heterosis. The crossings IC212140×IC138866, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC138866, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC82322×IC75310, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crosses.

Fourteen hybrids viz. IC212140×IC138866, IC212140×IC75310, IC212140×IC75310, IC82322×IC78751, IC82322×IC78801, IC82322×IC75310, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310 showed the desirable positive significant Heterobeltiosis (Table 4.4.4).

4.4.2 Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation in Meerut, Uttar Pradesh

4.4.2.1 Days to 75% flowering

Ten genotypes *viz.* IC212140×IC78737, IC532889×IC78751, IC82322×IC78751, IC82322×IC78737, IC78751×IC78737, IC138866×IC78737, IC138866×IC75310, IC138866×IC75310, IC55681×IC75310, IC55681×IC75310 were found negative significant and desirable for mid-parent heterosis. Nineteen hybrids *viz.* IC212140×IC55681, IC212140×IC75310, IC532889×IC78751, IC532889×IC78801, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC75310, IC78751×IC78737, IC78751×IC78801, IC138866×IC78737, IC138866×IC75310, IC138866×IC75310, IC78737×IC78801, IC78737×IC75310, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310 were found negative significant and desirable for heterobeltiosis.

For inbreeding depression, a positive magnitude is required for days to 75% flowering. According to Table 4.4.5, seventeen out of forty-five crosses demonstrated a favourable outcome.

4.4.2.2 Days to Maturity

The range for days to maturity varied from -2.64 to 1.51. Ten crosses viz. IC532889×IC78751, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC75310, IC78751×IC78737, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC55681×IC75310 showed the negative significant magnitude for heterosis. While thirty-five crosses showed the positive and undesirable magnitude for heterosis. Thirteen hybrids viz. IC212140×IC78751, IC212140×IC75310, IC532889×IC78751, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC75310, IC78751×IC78737, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC55681×IC75310, IC75310×IC75310 possessed negative significant heterobeltiosis (Table 4.4.5).

4.4.2.3 Plant height

Medium plant height is preferred in wheat, as indicated by negative heterosis and heterobeltiosis. Therefore, crosses exhibiting a significant negative magnitude are preferable.

Twenty hybrids showed negative significant heterosis in the F1 generation. The crosses IC212140×IC82322, IC212140×IC138866, IC212140×IC78801, IC532889×IC82322, IC532889×IC78737, IC532889×IC55681, IC532889×IC78801, IC532889×IC75310, IC532889×IC75310, IC82322×IC78801, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC55681×IC78801, IC55681×IC75310 showed negative significant heterosis, hence considered as desirable crosses.

Thirty hybrids viz. IC212140×IC82322, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC532889×IC82322, IC532889×IC138866, IC532889×IC78737, IC532889×IC55681, IC532889×IC78801, IC532889×IC75310, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC78737, IC138866×IC78801, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC75310, IC78801×IC75310 showed the negative significant heterobeltiosis (Table 4.4.5).

Table 4.4.5 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Days to 75% flowering, Days to Maturity and Plant Height in Meerut, Uttar Pradesh

Trait	Days to 75% flowering			Days to maturity			Plant height		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	5.75 **	4.66 **	-0.82	-0.76	-1.01	-0.13	6.24 **	0.54	1.16
IC212140×IC82322	1.77 **	1.06	-1.05	-0.51	-1.01	0.00	-23.02 **	-28.70**	1.39
IC212140×IC78751	-0.70	-0.70	-1.06	-0.63	-1.26 *	-0.76	22.29 **	18.63 **	0.00
IC212140×IC138866	14.94 **	6.34 **	-0.66	-0.51	-0.51	-1.41	15.40 **	13.99 **	-0.12
IC212140×IC78737	-1.05	-1.40	-0.71	0.00	-0.25	-1.52	-12.92 **	-16.93**	-0.80
IC212140×IC55681	8.84 **	-2.46 **	-1.08	1.91 **	1.78 **	0.00	13.74 **	13.11 **	0.70
IC212140×IC78801	10.24 **	-1.41	-0.71	0.51	0.25	1.01	-4.85 **	-11.91**	0.56
IC212140×IC75310	0.91	-2.46 **	-1.08	1.01 *	0.50	0.50	-0.87	-3.56 **	0.00
IC212140×IC75310	2.62 **	0.00	-1.41	-1.01 *	-1.75 **	-0.38	14.14 **	13.18 **	-0.76

IC532889×IC82322	0.70	-1.03	-0.70	-0.76	-1.01	1.15	-7.45 **	-18.51 **	-0.15
IC532889×IC78751	-2.79 **	-3.79 **	-1.08	-1.13 *	-1.51 **	-1.53	23.34 **	13.42 **	0.00
IC532889×IC138866	8.00 **	-1.03	-0.70	1.02 *	0.76	1.01	-31.17 **	-35.62 **	0.26
IC532889×IC78737	-0.35	-1.03	-1.05	0.51	0.51	1.39	-17.02 **	-24.89 **	0.12
IC532889×IC55681	11.07 **	-1.38	-1.05	-0.63	-0.76	0.89	-11.13 **	-16.34 **	0.74
IC532889×IC78801	6.61 **	-5.52 **	-1.09	0.00	0.00	0.00	-26.63 **	-35.43 **	-0.15
IC532889×IC75310	-0.18	-4.48 **	-0.72	0.76	0.50	0.00	-23.48 **	-29.44 **	1.37
IC532889×IC75310	4.02 **	0.34	-0.69	-1.26 **	-1.75 **	-0.77	-43.38 **	-46.85 **	-1.08
IC82322×IC78751	-2.48 **	-3.17 **	-1.09	-1.64 **	-1.76 **	-0.26	2.46 **	-2.31 **	-1.27
IC82322×IC138866	6.62 **	-0.71	-1.08	-1.27 **	-1.76 **	-0.51	15.87 **	8.57 **	0.34
IC82322×IC78737	-2.12 **	-3.15 **	-1.36	0.76	0.50	2.38	0.83	-2.24 **	0.32
IC82322×IC55681	10.50 **	-0.36	-1.08	0.38	0.00	0.00	2.36 **	-4.70 **	-0.26
IC82322×IC78801	9.52 **	-1.43	-1.09	-0.51	-0.76	-1.27	-2.67 **	-2.73 **	-0.51
IC82322×IC75310	0.55	-2.14 **	-0.73	-1.51 **	-1.51 **	-0.26	3.75 **	-1.37 **	1.26
IC82322×IC75310	0.82	-1.07	-1.44	-0.75	-1.00	-1.52	0.81	-5.89 **	-0.69
IC78751×IC138866	8.09 **	0.00	-1.76	0.38	-0.25	-0.76	5.41 **	3.51 **	0.13
IC78751×IC78737	-1.75 **	-2.10 **	-1.07	-1.13 *	-1.51 **	-1.02	17.63 **	15.61 **	0.34
IC78751×IC55681	11.20 **	-0.35	-1.06	0.00	-0.50	1.26	-3.09 **	-5.48 **	-0.87
IC78751×IC78801	8.66 **	-2.82 **	-1.09	-0.63	-1.01	1.27	-4.43 **	-8.93 **	-0.14
IC78751×IC75310	4.55 **	1.06	-1.05	-1.38 **	-1.51 **	-1.28	-11.79 **	-12.05 **	-0.31
IC78751×IC75310	4.79 **	2.11 **	-0.69	-0.13	-0.25	0.00	20.48 **	17.84 **	0.70
IC138866×IC78737	-6.73 **	-13.99 **	-1.22	-1.52 **	-1.77 **	-2.06	-0.79	-4.23 **	-0.41

IC138866×IC55681	5.04 **	1.45	-1.22	-2.16 **	-2.28 **	-1.56	7.33 **	6.59 **	0.80
IC138866×IC78801	4.40 **	0.62	-1.65	-0.25	-0.51	-2.29	-21.44 **	-26.43 **	0.08
IC138866×IC75310	-3.26 **	-7.55 **	-1.63	1.01 *	0.50	0.63	-5.96 **	-7.39 **	0.74
IC138866×IC75310	-6.07 **	-10.95 **	-1.67	-0.25	-1.00	1.14	-1.43 **	-1.82 **	0.06
IC78737×IC55681	11.94 **	0.00	-1.05	-0.38	-0.51	2.67	-13.30 **	-16.85 **	0.00
IC78737×IC78801	9.41 **	-2.45 **	-1.43	0.25	0.25	-1.26	-16.03 **	-18.64 **	0.30
IC78737×IC75310	2.00 **	-1.75 *	-1.07	-0.76	-1.01	0.76	-0.11	-2.12 **	-0.81
IC78737×IC75310	1.89 **	-1.05	-1.06	-0.25	-0.75	0.51	9.22 **	5.03 **	0.38
IC55681×IC78801	1.11	0.89	-1.76	0.13	0.00	-1.27	-4.80 **	-11.41 **	-0.42
IC55681×IC75310	-7.35 **	-14.34 **	-1.76	0.63	0.25	1.76	6.03 **	3.72 **	-0.27
IC55681×IC75310	-9.40 **	-16.88 **	-0.89	-1.64 **	-2.26 **	0.77	-3.16 **	-3.44 **	-1.48
IC78801×IC75310	5.52 **	-2.64 **	-1.16	0.76	0.50	3.26	4.99 **	-0.25	0.50
IC78801×IC75310	1.72 *	-6.86 **	-1.20	0.25	-0.25	-1.01	-0.53	-7.20 **	-0.27
IC75310×IC75310	1.78 *	0.93	-1.10	-1.26 **	-1.50 **	2.54	14.36 **	12.18 **	2.95

*Significance P ≤0.05; **Significance P ≤0.01

4.4.2.4 No. of spikelets /spike

The number of spikelets per spike is a beneficial factor for yield enhancement, correlated with a favourable heterosis effect.

Hence, crosses with positive significant heterosis are desirable. In F1 generation 19 crosses exhibited positive significant Heterosis. The crosses IC212140×IC138866, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC138866, IC82322×IC138866, IC82322×IC78737, IC82322×IC78801,IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC138866×IC75310, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC78801×IC75310 for heterosis whereas Eight hybrids viz. IC212140×IC78737, IC212140×IC78801, IC532889×IC138866, IC82322×IC78801, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, and

IC78801×IC75310 for heterobeltiosis, exhibited positive significant heterosis, hence deemed unfavorable for this characteristic (Table 4.4.6).

4.4.2.5 Number of grains per spike

An increased grain count per spike is advantageous for enhanced grain yield and correlates with positive heterosis and heterobeltiosis. Therefore, crosses exhibiting positive substantial effects are preferable. In the F1 generation, all crossings exhibited non-significant heterosis and heterobeltiosis, hence deemed undesirable for this characteristic (Table 4.4.6).

4.4.2.6. 1000-grain weight

The advantageous heterosis and heterobeltiosis are favourable for this characteristic. Therefore, crosses with a substantial positive magnitude are preferred. In the F1 generation, fifteen showed a positive significant magnitude.

The crosses IC212140×IC82322, IC212140×IC55681, IC212140×IC78801, IC532889×IC78737, IC82322×IC55681, IC138866×IC55681, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crossings. Eleven crosses viz. IC212140×IC82322, IC212140×IC55681, IC82322×IC55681, IC138866×IC55681, IC138866×IC78801, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, IC75310×IC75310 exhibited the positive heterobeltiosis (Table 4.4.6).

Table 4.4.6 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for No. of spikelets per spike, No. of grains per spike and 1000 seeds weight in Meerut, Uttar Pradesh

Trait	No. of spikelets per spike			No. grains per spike			1000 seeds weight		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	-6.54 *	-12.28**	2.00	9.20	2.15	-0.53	-3.73 **	-19.12 **	3.10
IC212140×IC82322	-0.97	-3.77	3.92	4.46	2.05	1.26	18.89 **	13.83 **	1.48
IC212140×IC78751	-5.50	-12.71**	4.85	-6.18	-10.22	4.19	-9.98 **	-16.54 **	8.49
IC212140×IC138866	9.43 **	3.57	12.07	-56.00**	-71.76 **	-0.81	1.03	-8.89 **	0.00

IC212140×IC78737	11.11 **	10.00 *	0.00	3.91	0.00	-0.27	-4.65 **	-11.27 **	3.58
IC212140×IC55681	2.97	1.96	-2.88	-32.08	-32.26	-2.38	25.87 **	24.42 **	2.22
IC212140×IC78801	10.89 **	9.80 *	8.93	-4.35	-5.38	-0.57	3.14 *	-5.38 **	-4.88
IC212140×IC75310	6.54 *	0.00	0.00	6.74	-2.15	-0.55	-5.33 **	-11.90 **	9.01
IC212140×IC75310	10.68 **	7.55	0.00	-15.76	-16.67	2.58	-12.63 **	-20.68 **	7.58
IC532889×IC82322	-10.91 **	-14.04**	0.00	-3.08	-11.28	0.00	-10.68 **	-22.13 **	-5.64
IC532889×IC78751	-12.07 **	-13.56**	0.00	15.06	12.35	0.52	-11.34 **	-20.38 **	-3.94
IC532889×IC138866	9.73 **	8.77 *	0.00	-42.72 *	-64.27 **	2.99	-7.64 **	-14.73 **	0.00
IC532889×IC78737	5.66	-1.75	0.00	-2.99	-5.81	1.23	3.68 **	-7.21 **	4.05
IC532889×IC55681	-9.26 **	-14.04**	0.00	-12.97	-18.38	-2.65	-8.10 **	-23.51 **	3.28
IC532889×IC78801	1.85	-3.51	0.00	-9.88	-14.84	-0.32	-6.39 **	-15.05 **	3.69
IC532889×IC75310	-12.28 **	-12.28**	0.00	-0.95	-3.09	-0.64	-22.24 **	-30.41 **	2.70
IC532889×IC75310	-3.64	-7.02	0.00	-12.79	-17.58	0.00	-0.17	-8.46 **	3.08
IC82322×IC78751	-8.93 **	-13.56**	0.00	-1.92	-8.21	0.84	-3.91 **	-7.09 **	-6.78
IC82322×IC138866	10.09 **	7.14	5.00	-47.29 *	-65.80 **	0.89	-11.67 **	-17.04 **	-2.23
IC82322×IC78737	11.76 **	7.55	0.00	-14.44	-19.49	1.27	0.57	-2.38	-4.07
IC82322×IC55681	0.00	-1.89	-7.69	-18.42	-20.51	0.00	15.76 **	9.61 **	0.77
IC82322×IC78801	13.46 **	11.32 **	6.78	13.53	9.74	0.00	-0.24	-4.62 **	-4.84
IC82322×IC75310	7.27 *	3.51	9.32	6.29	-4.62	0.54	-6.79 **	-9.52 **	-0.44
IC82322×IC75310	7.55 *	7.55	-1.75	-14.59	-17.44	1.24	-19.71 **	-24.06**	0.99
IC78751×IC138866	-14.78	-	-5.10	-	-79.69	4.51	-32.06	-	2.25

	**	16.95**		67.76**	**		**	34.07**	
IC78751×IC78737	3.70	-5.08	-3.57	-36.84	-37.21	2.78	-31.23 **	-31.50**	8.05
IC78751×IC55681	12.73 **	5.08	6.45	-44.79	-47.03	1.02	-39.06 **	-44.09**	7.04
IC78751×IC78801	14.55 **	6.78	-1.59	-38.07	-40.11	2.75	-38.91 **	-39.62**	11.46
IC78751×IC75310	-3.45	-5.08	-1.79	-40.92	-43.53	2.08	-28.06 **	-28.35**	6.59
IC78751×IC75310	10.71 **	5.08	4.84	-47.16	-48.9	2.15	-34.15 **	-35.64**	11.68
IC138866×IC78737	0.95	-5.36	-15.09	-58.65**	-73.89 **	4.68	1.92	-1.48	4.51
IC138866×IC55681	-2.80	-7.14	0.00	-60.71**	-74.81 **	3.64	24.48 **	11.11 **	4.00
IC138866×IC78801	-2.80	-7.14	-3.85	-66.31**	-78.47 **	0.00	20.00 **	17.78 **	15.72
IC138866×IC75310	7.96 *	7.02	-8.20	-44.44 *	-65.65 **	4.44	1.92	-1.48	5.26
IC138866×IC75310	22.94 **	19.64 **	12.69	-49.10 *	-67.48 **	-1.88	3.43 **	2.67	6.49
IC78737×IC55681	18.00 **	15.69 **	-16.95	1.96	-1.62	-2.20	5.17 **	-3.17 *	-4.10
IC78737×IC78801	-16.00 **	-17.65**	-7.14	4.52	1.65	-1.08	-17.89 **	-19.15**	-1.90
IC78737×IC75310	22.64 **	14.04 **	-1.54	-18.04	-22.09	3.73	-11.11 **	-11.11**	-26.79
IC78737×IC75310	-1.96	-5.66	0.00	-17.51	-19.78	4.11	-11.20 **	-13.53**	-20.87
IC55681×IC78801	0.00	0.00	6.86	-4.63	-5.41	0.29	27.12 **	15.38 **	-4.00
IC55681×IC75310	-3.70	-8.77 *	-2.88	12.35	3.24	3.66	25.00 **	15.08 **	-5.52
IC55681×IC75310	-1.92	-3.77	3.92	5.18	4.32	4.66	32.22 **	18.80 **	3.80
IC78801×IC75310	14.81 **	8.77 *	8.06	17.51	8.79	6.57	17.19 **	15.38 **	-5.33
IC78801×IC75310	5.77	3.77	3.64	-14.84	-14.84	-12.90	15.59 **	14.29 **	-1.97

IC75310×IC75310	-1.82	-5.26	7.41	-18.69	-24.73	1.46	5.79 **	3.01 *	5.11

*Significance P ≤0.05; **Significance P ≤0.01

4.4.2.7 Grain yield per plant

A greater grain yield is preferable, as shown by a positive magnitude. Hence, crosses with a positive significant magnitude are desirable. In the F1 generation, seventeen crosses showed positive significant heterosis. The crosses IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC138866, IC212140×IC78737, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78737, IC532889×IC75310, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC78737×IC55681, IC78737×IC75310, IC78737×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crossings.

Fifteen hybrids viz. IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC78737,IC212140×IC55681,IC212140×IC78801,IC212140×IC75310,IC212140 ×IC75310,IC82322×IC78751, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC78737×IC55681, IC78737×IC75310, IC78737×IC75310 exhibited the desirable positive heterobeltiosis (Table 4.4.7).

4.4.2.8 Spike length

Extended spike length is seen advantageous for increased grain yield and correlates with a positive magnitude. Therefore, crosses exhibiting positive substantial effects are preferable.

In the F1 generation, twenty-six crosses showed positive significant heterosis. The crosses, IC212140×IC78737, IC212140×IC55681, IC212140×IC75310,IC212140×IC75310, IC532889×IC78737, IC532889×IC75310, IC82322×IC78751, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC78737, IC78751×IC55681, IC78751×IC78801, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC138866×IC75310, IC78737×IC55681, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, and IC78801×IC75310 demonstrated strongly favourable heterosis, while ten crosses viz. IC82322×IC78751, IC82322×IC75310, IC82322×IC75310, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC78737×IC55681, IC78737×IC75310, IC55681×IC75310, and IC55681×IC75310 exhibited positive significant heterobeltiosis, thereby qualifying as desirable crosses (Table 4.4.7).

4.4.2.9 Number of tillers per plant

An increased number of tillers per plant is deemed advantageous and correlates with a positive magnitude. Therefore, parents and crosses exhibiting favourable substantial effects are preferred. In the F1 generation, twenty-six hybrids exhibited considerable positive heterosis.

The crossings IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC78737, IC532889×IC55681, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC75310, IC82322×IC75310, IC78751×IC138866, IC78751×IC78737, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC138866×IC55681, IC138866×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crosses.

Twenty crossings, namely IC212140×IC78737, IC212140×IC75310, IC212140×IC75310, IC532889×IC78751, IC532889×IC138866, IC532889×IC75310, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC75310, IC82322×IC75310, IC78751×IC138866, IC78751×IC78737, IC78751×IC55681, IC78751×IC75310, IC78751×IC75310, IC138866×IC78737, IC78737×IC55681, IC78801×IC75310, and IC75310×IC75310, exhibited considerable positive heterobeltiosis (Table 4.4.7).

Table 4.4.7 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Grain yield per plant, Spike length and No. of tillers per plant in Meerut, Uttar Pradesh

Trait	Grain yield per plant			Spike length			No. of tillers per plant		
Cross	H	HB	ID	H	HB	ID	H	HB	ID
IC212140×IC532889	7.84 **	5.77 **	-3.64	-10.51 **	-14.22 **	7.69	-20.41 **	-37.10**	7.69
IC212140×IC82322	25.89 **	17.50 **	2.84	0.66	-7.53 **	13.03	-25.58 **	-36.00**	6.25
IC212140×IC78751	17.18 **	8.13 **	4.51	-1.33	-6.47 **	-11.54	-25.30 **	-34.04**	6.45
IC212140×IC138866	5.63 **	-3.94 **	-5.74	-8.75 **	-12.79 **	15.04	-26.32 **	-40.68**	2.86
IC212140×IC78737	18.94 **	9.76 **	5.19	16.74 **	0.36	7.17	74.29 **	69.44 **	6.56
IC212140×IC55681	13.49 **	9.91 **	-5.74	2.94 **	-5.40 **	-37.07	6.06	-2.78	-5.71
IC212140×IC78801	18.94 **	9.76 **	4.44	-3.81 **	-4.68 **	0.00	27.66 **	3.45	6.67

IC212140×IC75310	13.12 **	6.84 **	-3.20	6.13 **	-0.36	7.22	81.82 **	53.85 **	5.00
IC212140×IC75310	12.39 **	4.10 **	0.79	2.72 **	-5.04 **	-7.58	55.56 **	40.00 **	7.94
IC532889×IC82322	-4.55 **	-12.50 **	4.76	-18.44 **	-21.99 **	-3.86	-17.86 **	- 25.81**	8.70
IC532889×IC78751	-0.45	-9.76 **	9.91	-11.97 **	-19.83 **	4.12	63.30 **	43.55 **	7.87
IC532889×IC138866	-3.96 **	-14.17 **	11.01	-8.24 **	-8.52 **	14.34	38.84 **	35.48 **	7.14
IC532889×IC78737	6.73 **	-3.25 *	-6.72	9.32 **	-9.27 **	18.18	16.67 **	-9.68 **	8.93
IC532889×IC55681	-1.42	-6.31 **	8.65	-13.08 **	-23.13 **	-8.58	10.87 **	- 17.74**	0.00
IC532889×IC78801	-11.21 **	-19.51 **	6.06	-20.15 **	-24.12 **	-17.39	0.00	-3.23	6.67
IC532889×IC75310	1.38	-5.98 **	9.09	-8.24 **	-17.19 **	-11.95	33.33 **	22.58 **	7.89
IC532889×IC75310	-12.61 **	-20.49 **	4.12	7.59 **	-4.32 **	13.79	-8.41 **	- 20.97**	14.29
IC82322×IC78751	4.53 **	3.25 *	-1.57	16.01 **	1.51 *	5.93	95.88 **	90.00 **	-3.16
IC82322×IC138866	2.02	-0.79	-6.35	-10.83 **	-14.46 **	-10.56	68.81 **	55.93 **	6.52
IC82322×IC78737	-25.93 **	-26.83 **	8.89	9.02 **	-12.65 **	6.90	76.19 **	48.00 **	5.41
IC82322×IC55681	8.23 **	4.17 **	8.00	17.17 **	-0.30	12.08	25.00 **	0.00	14.00
IC82322×IC78801	8.64 **	7.32 **	7.58	5.79 **	-3.61 **	9.38	-14.81 **	- 20.69**	15.22
IC82322×IC75310	17.30 **	15.83 **	2.88	35.76 **	17.77 **	25.58	23.53 **	21.15 **	9.52
IC82322×IC75310	-18.18 **	-18.85 **	6.06	21.13 **	3.61 **	14.53	17.89 **	12.00 **	-1.79
IC78751×IC138866	-47.20 **	-48.03 **	-7.58	-10.83 **	-19.02 **	0.00	26.42 **	13.56 **	-4.48
IC78751×IC78737	-52.03 **	-52.03 **	3.39	9.13 **	-1.61	-4.08	53.09 **	31.91 **	-4.84
IC78751×IC55681	-36.75	-39.84	8.11	13.28	9.64 **	7.33	32.47	8.51 *	0.00

	**	**		**			**		
IC78751×IC78801	-46.34 **	-46.34 **	0.00	2.68 **	-1.83 *	-3.73	-8.57 **	-17.24**	8.33
IC78751×IC75310	-49.17 **	-50.41 **	-8.20	10.75 **	9.64 **	7.33	17.17 **	11.54 **	-12.07
IC78751×IC75310	-46.94 **	-47.15 **	-7.69	27.42 **	24.10 **	12.94	10.87 **	8.51 *	-11.76
IC138866×IC78737	-3.20 *	-4.72 **	-2.48	6.14 **	-12.13 **	0.00	67.74 **	32.20 **	10.26
IC138866×IC55681	0.84	-5.51 **	2.50	3.35 **	-8.85 **	0.00	39.33 **	5.08	-12.90
IC138866×IC78801	0.80	-0.79	3.97	-13.49 **	-18.03 **	4.00	-16.24 **	-16.95**	-8.16
IC138866×IC75310	-0.82	-4.72 **	3.31	-2.37 **	-12.13 **	3.73	-17.12 **	-22.03**	-21.74
IC138866×IC75310	-8.43 **	-10.24 **	2.63	10.54 **	-1.97 **	3.34	13.46 **	0.00	10.17
IC78737×IC55681	10.26 **	4.88 **	4.65	14.55 **	6.44 **	-4.03	-6.25	-11.76 *	-13.33
IC78737×IC78801	1.63	1.63	5.60	-0.21	-13.55 **	-25.42	-34.78 **	-48.28**	-10.00
IC78737×IC75310	9.17 **	6.50 **	6.87	13.96 **	3.69 **	-11.86	-41.86 **	-51.92**	-32.00
IC78737×IC75310	6.94 **	6.50 **	6.87	-7.34 **	-14.41 **	-29.70	-8.86 *	-20.00**	8.33
IC55681×IC78801	-13.68 **	-17.89 **	8.91	2.77 **	-4.76 **	-11.54	-20.45 **	-39.66**	5.71
IC55681×IC75310	-8.77 **	-11.11 **	10.58	12.79 **	10.25 **	-18.59	-9.76 *	-28.85**	8.11
IC55681×IC75310	-6.44 **	-10.66 **	11.01	19.40 **	18.64 **	-10.71	-20.00 **	-33.33**	-16.67
IC78801×IC75310	-2.50	-4.88 **	5.13	5.22 **	-0.37	14.71	21.82 **	15.52 **	-4.48
IC78801×IC75310	-0.41	-0.81	4.10	-2.55 **	-9.16 **	-12.10	20.39 **	6.90 *	-16.13
IC75310×IC75310	-12.13 **	-13.93 **	-8.57	-3.75 **	-5.33 **	-17.32	15.46 **	7.69 *	5.36

*Significance P ≤0.05; **Significance P ≤0.01

4.4.2.10 Harvest index

Positive heterosis and heterobeltiosis are advantageous for this feature. Therefore, crossings with a positively significant magnitude are preferred.

In the F1 generation, thirteen crosses exhibited considerable positive heterosis. The crosses IC212140×IC532889, IC212140×IC82322, IC212140×IC78751, IC212140×IC78737, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC532889×IC82322, IC532889×IC78737, IC532889×IC55681, IC532889×IC75310, IC532889×IC75310, and IC78751×IC55681 demonstrated significant positive heterosis, thus classified as desirable crosses. In contrast, eight crosses, namely IC212140×IC82322, IC212140×IC78751, IC212140×IC55681, IC212140×IC78801, IC212140×IC75310, IC532889×IC78737, IC532889×IC55681, and IC532889×IC75310, exhibited significant positive heterobeltiosis (Table 4.4.8).

Table 4.4.8 Estimates of Heterosis (H) and Heterobeltiosis (HB) in F_1 and inbreeding depression in F_2 generation for Harvesting Index and Biological Yield in Meerut, Uttar Pradesh

Trait	Harvesting Index			Biological Yield		
Cross	H	HB	ID	H	HB	ID
IC212140×IC532889	13.17 **	3.13	-4.77	-5.42 **	-12.26 **	1.08
IC212140×IC82322	40.45 **	21.72 **	5.32	-13.43 **	-29.21 **	-2.64
IC212140×IC78751	35.52 **	33.82 **	2.27	-13.62 **	-21.21 **	2.31
IC212140×IC138866	-18.94 **	-23.36**	-8.07	30.63 **	25.34 **	2.16
IC212140×IC78737	8.85 **	-1.36	3.85	7.19 **	-9.60 **	1.40
IC212140×IC55681	22.80 **	11.19 **	-7.22	-8.89 **	-19.83 **	1.39
IC212140×IC78801	14.93 **	13.73 **	4.13	3.58 **	-3.49 **	0.33
IC212140×IC75310	4.46 **	3.46 *	-5.19	8.22 **	1.28	1.90
IC212140×IC75310	0.54	-1.41	2.25	11.59 **	1.51 *	-1.48
IC532889×IC82322	9.30 **	3.37	2.65	-13.40 **	-24.53 **	2.17
IC532889×IC78751	3.22	-4.85 **	8.76	-3.40 **	-5.15 **	1.28
IC532889×IC138866	-6.93 **	-19.36**	8.68	2.61 **	-0.94	2.54
IC532889×IC78737	45.87 **	44.97 **	-5.13	-26.89 **	-34.09 **	-1.53
IC532889×IC55681	20.70 **	19.84 **	8.67	-18.34 **	-22.91 **	0.00
IC532889×IC78801	-9.69 **	-18.48**	5.42	-1.74 **	-2.20 **	0.64
IC532889×IC75310	5.30 **	-3.19	10.54	-3.81 **	-4.72 **	-1.65
IC532889×IC75310	17.57 **	9.10 **	5.31	-25.54 **	-27.11 **	-1.24
IC82322×IC78751	-11.82 **	-22.74**	-3.47	16.36 **	3.04 **	1.81
IC82322×IC138866	-12.51 **	-27.67**	-9.31	12.15 **	-5.14 **	2.71
IC82322×IC78737	-27.82 **	-31.33**	9.12	2.43 **	-1.40 **	-0.24

IC82322×IC55681	-0.36	-5.13 *	8.87	8.14 **	-0.70	-0.94
IC82322×IC78801	-11.37 **	-23.87**	7.56	19.52 **	3.74 **	0.00
IC82322×IC75310	-3.60 *	-15.76**	1.95	18.92 **	2.80 **	0.91
IC82322×IC75310	-22.03 **	-31.27 **	6.28	3.16 **	-8.41 **	-0.26
IC78751×IC138866	-12.46 **	-18.21 **	-3.78	-39.94 **	-43.03 **	-3.72
IC78751×IC78737	-12.77 **	-20.03 **	2.87	-45.45 **	-50.00 **	0.51
IC78751×IC55681	6.76 **	-2.22	1.80	-40.99 **	-43.30 **	6.40
IC78751×IC78801	-9.45 **	-11.51 **	-0.54	-40.78 **	-42.12 **	0.52
IC78751×IC75310	-12.28 **	-12.54 **	-6.47	-42.06 **	-43.64 **	-1.61
IC78751×IC75310	-20.88 **	-21.44 **	-5.77	-32.93 **	-33.13 **	-1.80
IC138866×IC78737	1.60	-12.42 **	-4.21	-6.94 **	-18.69 **	1.55
IC138866×IC55681	2.43	-11.78 **	0.29	-3.06 **	-11.45 **	2.21
IC138866×IC78801	-5.10 **	-9.37 **	-0.12	6.06 **	2.86 **	4.01
IC138866×IC75310	-4.46 **	-10.48 **	2.67	3.62 **	0.96	0.63
IC138866×IC75310	-8.55 **	-15.12 **	0.66	-0.32	-5.72 **	1.92
IC78737×IC55681	0.42	0.32	2.02	9.81 **	4.55 **	2.66
IC78737×IC78801	-13.87 **	-22.68 **	2.69	16.46 **	4.55 **	2.90
IC78737×IC75310	-6.80 **	-14.80 **	4.50	15.82 **	3.54 **	2.44
IC78737×IC75310	-3.64 *	-11.09 **	7.57	10.16 **	1.26 *	-0.75
IC55681×IC78801	-17.14 **	-25.68 **	8.02	3.42 **	-2.79 **	0.86
IC55681×IC75310	-24.65 **	-31.17 **	10.58	20.30 **	12.57 **	0.00
IC55681×IC75310	-17.06 **	-23.54 **	11.72	12.46 **	8.38 **	-0.77
IC78801×IC75310	-6.50 **	-8.36 **	4.89	4.31 **	3.81 **	0.31
IC78801×IC75310	-2.15	-5.04 **	32.20	1.70 **	-0.90	-302.74
IC75310×IC75310	-14.79 **	-15.64 **	-9.55	3.11 **	0.00	0.90

*Significance P ≤0.05; **Significance P ≤0.01

4.4.2.11 Biological yield

Positive heterosis and heterobeltiosis are advantageous for this feature. Therefore, crosses with a substantial positive magnitude are preferable. Twenty-five crosses in F1 exhibited considerable positive heterosis. The crossings IC212140×IC138866, IC212140×IC78737, IC212140×IC78801, IC212140×IC75310, IC212140×IC75310, IC532889×IC138866, IC82322×IC78751, IC82322×IC138866, IC82322×IC78737, IC82322×IC55681, IC82322×IC78801, IC82322×IC75310, IC82322×IC75310, IC138866×IC78801, IC138866×IC75310, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC78801, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310, IC78801×IC75310, and IC75310×IC75310 exhibited considerable positive heterosis, therefore deemed as favourable crosses.

Thirteen hybrids viz. IC212140×IC138866, IC212140×IC75310, IC82322×IC78751, IC82322×IC78801, IC82322×IC75310, IC138866×IC78801, IC78737×IC55681, IC78737×IC78801, IC78737×IC75310, IC78737×IC75310, IC55681×IC75310, IC55681×IC75310, IC78801×IC75310 showed the desirable positive significant Heterobeltiosis (Table 4.4.8).

4.5 Heritability and Genetic Advancement in Both Generations

Heritability (Broad sense) and Genetic advance provide the index of transmissibility of attributes and are used as direct selection parameters. Based on the findings of this study, it is evident that the majority of the traits examined have a significant genetic basis. High heritability was observed for all the attributes studied in both the F1 and F2 generations in Punjab (Fig. 4.5.1.).

The F1 generation in Meerut, Uttar Pradesh also showed high heritability for all eleven attributes while, the F2 generation demonstrated high heritability was observed for days to 75% flowering, plant height, 1000 seed weight, and grain yield per plant (99%), followed by number of shoots per plant (98.70%), spike length (84.60%) and number of spikelets per ear (82.80%). Nonetheless, the heritability of spikelets per ear and days to maturity was rather low (17.40%, 20.20%), but biological yield exhibited moderate heritability (43.70%) shown in (fig. 4.5.1).

Furthermore, a significantly high genetic progress, represented as a percentage of the mean, was seen for the number of tillers per plant, grain production per plant, 1000-seed weight, followed by harvest index, plant height, biological yield, spike length, and number of spikelets per spike. In contrast, little genetic improvements were noted in days to maturity across both generations in Punjab and Meerut, Uttar Pradesh (Fig. 4.5.2).

4.5.1 Heritability and genetic advancement in both generations especially of the characters in Punjab and Meerut, Uttar Pradesh

S. No.	Characters	$h^2_{(bs)}$ (%)	GAM (%)	$h^2_{(bs)}$ (%)	GAM (%)	$h^2_{(bs)}$ (%)	GAM (%)	$h^2_{(bs)}$ (%)	GAM (%)
		F_1 (Punjab)		F_2 (Punjab)		F_1 (U.P.)		F_2 (U.P.)	
1	Days to 75% flowering	0.99	15.19	0.99	15.35	0.99	15.48	0.99	15.19
2	Days to maturity	0.79	1.46	0.82	1.81	0.76	1.27	0.43	1.04
3	Plant height	0.99	29.90	0.99	29.80	0.99	30.12	0.99	29.99
4	No. of spikelets/spike	0.92	15.64	0.89	17.05	0.91	16.61	0.82	15.62

5	No. of grains/spike	0.99	38.02	0.99	38.20	0.99	38.61	0.17	14.93
6	1000 seeds weight	0.99	33.57	0.99	34.26	0.99	33.96	0.99	36.74
7	Grain yield/plant	0.99	36.17	0.98	34.29	0.99	36.97	0.99	37.67
8	Spike length	0.99	23.63	0.92	26.60	0.99	26.35	0.84	17.54
9	No. of tillers/plant	0.99	62.07	0.98	11.13	0.99	65.20	0.98	62.93
10	Harvesting index	0.99	32.72	0.98	31.28	0.99	33.05	0.93	35.29
11	Biological yield	1.00	42.78	0.99	42.08	1.00	43.20	0.20	18.30

h^2 (bs) = Heritability in broad sense; GAM = Genetic advancement in percentage of mean

Significant heritability and substantial genetic advancement as a percentage of the mean were seen for the number of tillers per plant, grain production per plant, 1000-seed weight, harvesting index, plant height, and biological yield in both the Punjab and Meerut generations (Mathew et al., 2018, Ishaaq et al., 2022).

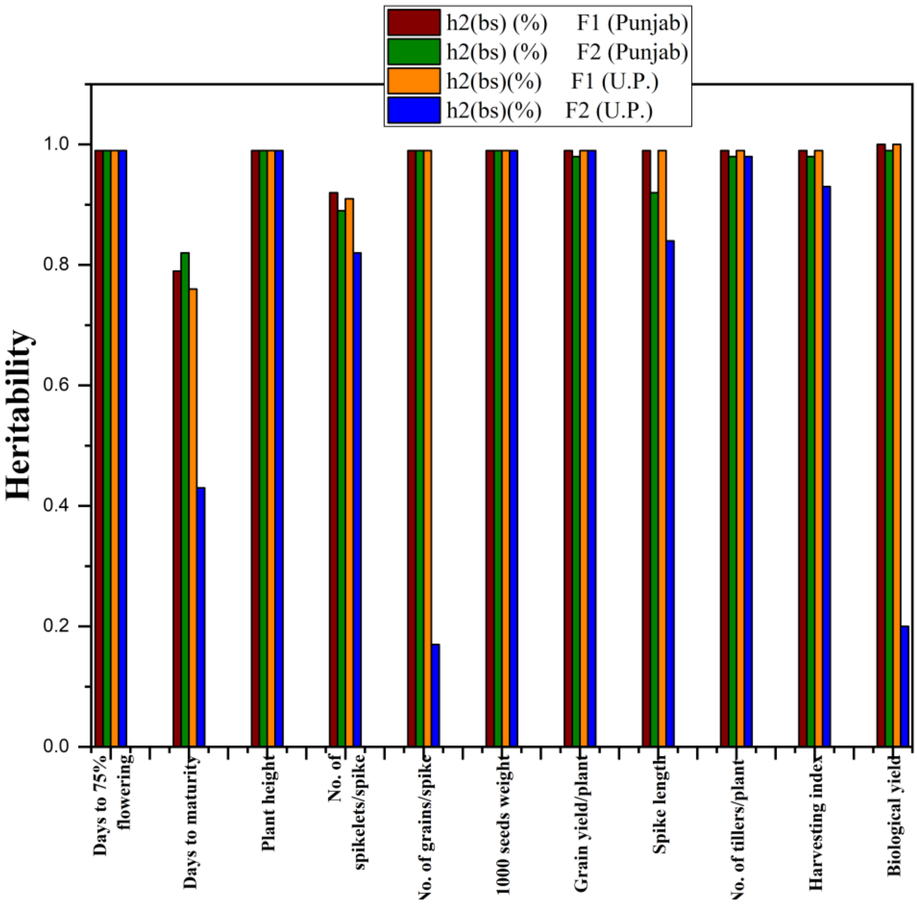

Figure 4.5.1. Heritability (Broad sense) in both F1 and F2 generations (Punjab & U.P.)

High heritability coupled with modest genetic advance estimates was noted for days to 75% blooming, days to maturity, and the number of spikelets per spike in Punjab and the F1 generation in Meerut. Low heritability and minimal genetic advancement were detected for biological yield, number of spikelets per spike, and days to maturity in the F2 generation in Meerut. Shamuyarira et al. (2019) also found similar results.

Similar studies showed that direct selection could be more beneficial for traits with high genetic advance estimates with high heritability as the additive gene action governed them (Farshadfar et al. 2014; Okechukwu et al. 2015; Abraha et al. 2017; Semahegn et al. 2021).

The results of the analysis of variance (ANOVA) for treatment, parents (except for days to maturity), and cross-overs showed high significance for all the attributes studied in both Punjab and Meerut, Uttar Pradesh trials (Table 4.2.1 and 4.2.2). Significant differences were observed in the mean squares for the parent vs. hybrid components across all studied traits. Comparable results were noted by Breeders (Gomaa et al. 2014; Qabil 2017; Farhat & Mohamed 2018; Khokhar et al. 2019; Kumar et al. 2020; and El-Nahas et al. 2021).

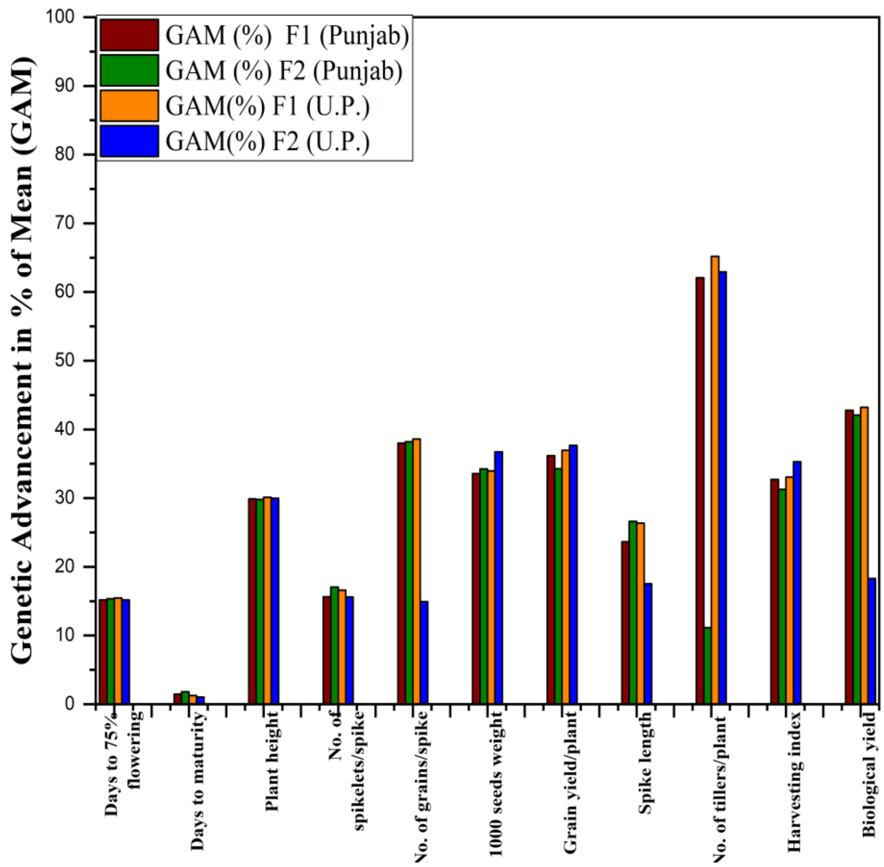

Figure 4.5.2. Genetic advancement as percentage of mean in F1 and F2 generation (Punjab & U.P.).

The current study revealed that cross-combination produced significant results for the majority of features concerning Specific Combining Ability effects. The results align with prior observations documented by wheat breeders (Ahmad et al. 2016, Khokar et al. 2019, El-Nahas 2021).

A comparison of substantial Mid Parent Heterosis and Heterobeltiosis (Better Parent Heterosis) was conducted for 11 characteristics across 45 crosses under drought stress conditions (Tables 4.4.1 to 4.4.8). Similar findings were noted by wheat breeders (Gimenez et al. 2021, Panhwar et al. 2024, El-Nahas et al. 2021, Thomas et al. 2017, Kumar et al. 2020, Attri et al. 2021, Ishaaq et al. 2022, Bhumika et al. 2018, Mwadzingeni et al. 2018) and in other crops (Ojo et al. 2007, Salem et al. 2022).

Chapter 5

Summary and Conclusion

The study titled "GENETIC EVALUATION OF GENOTYPES IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA FOR DROUGHT TOLERANCE IN WHEAT (*Triticum aestivum* L.)" aimed to analyse various factors such as component of variance, combining ability, heterosis, inbreeding depression, heritability and genetic advancement in under drought stress conditions. The experimental material comprised 10 parents, and their 45 cross combinations produced through the half-diallel crossing method (without reciprocals) in *Rabi* 2017-18, 2018-19, and 2019-20 at agriculture research farms, Lovely Professional University Phagwara Punjab and Meerut, Uttar Pradesh. The experiment was set up using a Randomized complete block design with three replications. The data was recorded for eleven characters. Statistical analysis was conducted on the data to determine the significance of differences (Panse and Sukhatme, 1967). The study also involved evaluating combining ability using Griffing's method 2, Model I. Additionally, genetic variance components, heterosis (Fonseca and Patterson, 1968), heritability, and inbreeding depression were estimated as well.

The following are the key findings from the current study:

The variance analysis for all attributes indicated that the mean squares attributable to genotypes were extremely significant for all examined traits in both sites.

The analysis of variance also depicted substantial differences among all the characters in treatments, parents, hybrids, and parents vs. hybrids in both Punjab and Uttar Pradesh trials under drought stress conditions. The substantial mean sum of squares differences for the assessed attributes among parents demonstrated that the material used in this study had adequate variability for diverse attributes.

The estimations of $\sigma 2A$ were positive in magnitude for all of the traits. For all traits in Punjab and Meerut, U.P., the magnitude of $\sigma 2D$ exceeded that of $\sigma 2A$, with the exceptions of Days to 75% blooming in both locations and No. of spikelets/spike in U.P., where $\sigma 2A$ surpassed $\sigma 2D$. Traits like days to 75% flowering, plant height, 1000-seeds weight, spike length, harvesting index, and biological yield showed the high narrow-sense heritability estimates (>30%) in both Punjab as well as Meerut, Uttar Pradesh trials. Because additive gene activity governs these traits, can be employed for direct selection.

The variance analysis for combining ability indicated substantial GCA differences for all traits and notable SCA variations for the majority of traits, with the exception of number of grains per spike in Meerut Uttar Pradesh. The ANOVA demonstrated the impact of both additive and dominant gene activity on the expression of different phenotypes. For every character analysed, the GCA / SCA variance ratio was below on, indicating the significance of non-additive gene activity.

General combining ability estimates showed parent IC138866, IC532889, IC82322, and IC55681 as desirable general combiners for various traits. It is therefore possible to make full use of these parents in hybridisation in order to produce lines that possess desirable characteristics, leading to increased wheat production.

Table 5.1 Top three performers for GCA and specific combining ability (SCA) effects in F1 generation

Characters	GCA		SCA	
	Punjab	Uttar Pradesh	Punjab	Uttar Pradesh
Days to 75% flowering	IC75310, IC75310, IC138866	IC55681, IC78801, IC75310	IC532889×IC75310, IC212140×IC82322, IC78801×IC75310	IC138866×IC78801, IC78801×IC75310, IC532889×IC75310
Days to Maturity	IC138866	IC138866	IC78737×IC75310, IC78751×IC75310, IC75310×IC75310	IC532889×IC75310, IC212140×IC532889, IC82322×IC78751
Plant height	IC532889, IC138866, IC55681	IC532889, IC138866, IC55681	IC212140×IC78801, IC82322×IC75310, IC138866×IC75310	IC82322×IC75310, IC212140×IC78801, IC138866×IC75310
No. of Spikelets /Spike	IC78751, IC138866, IC75310	IC78751, IC138866	IC78751×IC78801, IC138866×IC75310, IC78737×IC75310	IC78751×IC55681, IC138866×IC75310, IC78737×IC75310
No. of grains/spike	IC212140, IC82322, IC138866	IC138866	IC532889×IC138866, IC532889×IC78751, IC138866×IC75310	
1000 seeds weight	IC532889, IC138866, IC78801	IC532889, IC55681, IC75310	IC212140×IC82322, IC138866×IC78801, IC55681×IC75310	IC212140×IC82322, IC138866×IC78801, IC55681×IC75310
Grain yield/plant	IC212140, IC82322,	IC212140, IC82322, IC78737	IC212140×IC78751, IC532889×IC78751,	IC212140×IC78751, IC82322×IC78751,

	IC138866		IC82322×IC78751	IC82322×IC75310
Spike length	IC82322, IC138866	IC82322, IC138866	IC532889×IC78737, IC82322×IC75310, IC78751×IC75310	IC212140×IC78737, IC82322×IC75310, IC82322×IC75310
No. of tillers /plant	IC532889, IC82322, IC138866	IC532889, IC82322, IC138866	IC212140×IC75310, IC532889×IC78751, IC82322×IC78751	IC82322×IC78751, IC212140×IC75310, IC82322×IC138866
Harvesting Index	IC212140, IC532889, IC138866	IC212140, IC532889,IC138866	IC212140×IC82322, IC212140×IC78751, IC532889×IC78737	IC212140×IC78751, IC212140×IC82322, IC532889×IC78737
Biological yield	IC82322, IC78737, IC55681	IC82322, IC55681, IC75310	IC212140×IC138866, IC212140×IC78737, IC212140×IC75310	IC532889×IC78751, IC82322×IC78751, IC212140×IC138866

Specific combining ability showed the crosses IC82322×IC78751, IC212140×IC78751, IC82322×IC75310, IC138866×IC78837 in both Punjab and Meerut trials, appeared most favorable for grain yield per plant including some related traits. With further wheat breeding efforts, these crosses have a strong chance of increasing grain output (Table 5.1).

Based on the top three heterosis and heterobeltiosis cross performers, IC 212140×IC78737, IC55681×IC78837, and IC82322×IC78751 showed promising significant results for grain yield per plant and other traits whereas, IC138866×IC78837showed promising results for different attributes (Table 5.2).

Table 5.2 Top 3 Performers of heterosis over Mid-parent and better parent in F1 generation

Characters	Punjab		Uttar Pradesh	
	MPH	BPH	MPH	BPH
Days to 75% flowering	IC212140×IC78737, IC78751×IC78737, IC82322×IC78751	IC212140×IC78801, IC212140×IC78737, IC78737×IC75310	IC78751×IC78737, IC82322×IC78737, IC82322×IC78751	IC78751×IC78737, IC78737×IC75310, IC82322×IC75310
Days to Maturity	IC78751×IC78737, IC532889×IC55681,	IC78751×IC78737, IC212140×IC532889, IC212140×IC82322	IC212140×IC75310, IC532889×IC78751,	IC55681×IC75310, IC138866×IC55681,

	IC532889×IC75310		IC532889×IC75310	IC75310×IC75310
Plant height	IC55681×IC75310, IC138866×IC78737, IC138866×IC75310	IC82322×IC75310, IC138866×IC75310, IC78737×IC75310	IC78751×IC55681, IC82322×IC78801, IC138866×IC75310	IC78737×IC75310, IC82322×IC75310, IC138866×IC75310
No. of Spikelets /Spike	IC138866×IC75310, IC78737×IC55681, IC78737×IC75310	IC532889×IC138866, IC138866×IC75310, IC138866×IC75310	IC138866×IC75310, IC78737×IC55681, IC78737×IC75310	IC82322×IC78801 ,IC78751×IC78737, IC78751×IC75310
No. of grains/spike	IC532889×IC138866, IC82322×IC138866, IC138866×IC75310	IC212140×IC55681, IC138866×IC78801, IC55681×IC75310	IC532889×IC78751, IC78801×IC75310, IC82322×IC78801	IC532889×IC78751, IC82322×IC78801, IC78801×IC75310
1000 seeds weight	IC212140×IC55681, IC55681×IC78801, IC55681×IC75310	IC212140×IC82322, IC212140×IC55681, IC82322×IC75310	IC212140×IC55681, IC55681×IC78801, IC55681×IC75310	IC212140×IC55681, IC138866×IC78801, IC55681×IC75310
Grain yield/plant	IC212140×IC82322, IC212140×IC78737, IC212140×IC78801	IC82322×IC75310, IC78751×IC75310, IC55681×IC75310	IC212140×IC78737, IC212140×IC78801, IC82322×IC75310	IC212140×IC82322, IC212140×IC78737, IC82322×IC75310
Spike length	IC82322×IC75310, IC82322×IC75310, IC78751×IC75310	IC212140×IC78737, IC82322×IC78751, IC82322×IC138866	IC82322×IC75310, IC78751×IC75310, IC55681×IC75310	IC82322×IC75310, IC78751×IC75310, IC78751×IC7531

				0
No. of tillers /plant	IC212140×IC75310, IC82322×IC78751, IC82322×IC78737	IC212140×IC78751, IC212140×IC82322, IC532889×IC78737	IC212140×IC75310, IC82322×IC78751, IC82322×IC78737	IC212140×IC78737, IC82322×IC78751, IC82322×IC138866
Harvesting Index	IC212140×IC82322, IC212140×IC78751, IC532889×IC78737	IC212140×IC138866, IC55681×IC75310, IC55681×IC75310	IC212140×IC82322, IC212140×IC78751, IC532889×IC78737	IC212140×IC78751, IC532889×IC78737, IC212140×IC82322
Biological yield	IC212140×IC138866, IC82322×IC78801, IC55681×IC75310	IC212140×IC55681,IC532889×IC138866, IC78801×IC75310	IC212140×IC78751, IC212140×IC78737, IC212140×IC75310	IC55681×IC75310, IC55681×IC75310, IC212140×IC78751

In the present investigation, most of the traits showed desirable inbreeding depression for most of the traits. For the grain yield per plant crosses, IC82322×IC78551 showed the desirable inbreeding depression in both trials whereas, IC138866×IC78837, IC 212140×IC78737, IC55681×IC78837 exhibited the desirable outcome.

The most heritable characteristics were the height of the plant, the weight of one thousand seeds, the amount of grain produced by each plant, the number of tillers produced by each plant, and the harvesting index. There was a significant genetic advance as a percentage of the mean. Due to the fact that these characteristics are governed by additive gene activity, they can also be used for direct selection procedures.

Bibliography

1. Abdul Hamid, M. I. E., Qabil, N., & El-Saadony, F. M. A. (2017). Genetic variability, correlation and path analyses for yield and yield components of some bread wheat genotypes. *Journal of Plant Production*, *8*(8), 845-852.
2. Abraha, M. T., Hussein, S., Laing, M., & Assefa, K. (2017). Genetic variation and trait association of *tef ['Eragrostis tef'*(Zucc.) Trotter] evaluated under optimal and moisture stressed environments. *Australian journal of crop science*, *11*(3), 241-247.
3. Ahmad, F., Mohammad, F., Bashir, M., & Khan, H. (2007). Inheritance of important traits in bread wheat over different planting dates using diallel analysis. *Sarhad Journal of Agriculture (Pakistan)*, **23** (4): 955-963.
4. Ahmad, A., Aslam, Z., Javed, T., Hussain, S., Raza, A., Shabbir, R., & Tauseef, M. (2022). Screening of wheat (*Triticum aestivum* L.) genotypes for drought tolerance through agronomic and physiological response. *Agronomy*, *12*(2), 287.
5. Ahmad, E., Kamar, A., Jaiswal, J.P. (2016) Identifying heterosis combinations for yield and quality traits in bread wheat (*Triticum aestivum* L.). Electronic Journal of Plant Breeding, 7(2), 352-361.
6. Ajmal, S.U., Zakir, N., & Mujahid, M. Y. (2009). Estimation of genetic parameters and character association in wheat. *Journal of agricultural and biological science*, *1*(1), 15-18.
7. Al-Salimiyia, M., De Luigi, G., Abu-Rabada, E., Ayad, H., & Basheer-Salimia, R. (2018). Adaption of wheat genotypes to drought stress. *International Journal of Environment, Agriculture and Biotechnology*, *3*(1), 182-186.
8. Alemu, Y. A., Anley, A. M., & Abebe, T. D. (2020). Genetic variability and association of traits in Ethiopian durum wheat (*Triticum turgidium* L. var. *durum*) landraces at Dabat Research Station, North Gondar. *Cogent Food & Agriculture*, *6*(1), 1778604.
9. Ashfaq, W., Ul-Allah, S., Kashif, M., Sattar, A., & Nabi, H. G. (2016). Genetic variability study among wheat genotypes under normal and drought conditions. *J. Glob. Innov. Agric. Soc. Sci*, *4*(3), 111-116.
10. Attri, H., Dey, T., Singh, B., & Kour, A. (2021). Genetic estimation of grain yield and its attributes in three wheat (*Triticum aestivum* L.) crosses using six parameter model. *Journal of Genetics*, *100*, 1-9.

11. Bandyopadhyay, B. B. (2008). Genetic variation in wheat upon water deficit stress to a range of low temperature regime at high altitude. *Indian Journal of Genetics and Plant Breeding*, *68*(01), 26-32.

12. Bao, Y. G., Sen, W., Wang, X. Q., Wang, Y. H., Li, X. F., Lin, W., & Wang, H. G. (2009). Heterosis and combining ability for major yield traits of a new wheat germplasm shannong 0095 derived from *Thinopyrum intermedium*. *Agricultural Sciences in China*, *8*(6), 753-760.

13. Bayisa, T., Tefera, H., & Letta, T. (2020). Genetic variability, heritability and genetic advance among bread wheat genotypes at Southeastern Ethiopia. *Agriculture, Forestry and Fisheries*, *9*(4), 128.

14. Bhumika, N.P., Desai, Rudranaik, S.A.V., Biradar, S.S., Arpitha, H.R., Kumar, A. (2018) Combining ability analysis for yield and spot blotch disease resistance in tetraploid wheat. International Journal of Current Microbiology and Applied Sciences, 7(1), 1843- 1847.

15. Bhushan, B., Gaurav, S. S., Kumar, R., Pal, R., Panday, M., Kumar, A., & Rahul, V. P. (2013). Genetic variability, heritability and genetic advance in bread wheat (*Triticum aestivum* L.). *Environment & Ecology*, *31*(2), 405-407.

16. Burungale, S. V., Chauhan, R. M., Gami, R. A., Thakor, D. M., & Patel, P. T. (2011). Combining ability analysis for yield, its components and quality traits in bread wheat (*Triticum aestivum* L.). *Crop Research*, *42*(1-3), 241-245.

17. Dagustu, N. (2009). Combining ability analysis in relation to heterosis for grain yield per spike and agronomic traits in bread wheat (*Triticum aestivum* L.). *Turkish Journal of Field Crops*, *13*(2), 49-61.

18. Donald CM and Hamblin J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Advances in. Agronomy* **28:**361-405.

19. East EM. 1936. Heterosis. *Genetics* 26, 375-397

20. El Nahas, M. M., & Ali, O. A. (2021). Estimation of combining ability and heterosis for wheat yield and its components under water stress conditions. *Egyptian Journal of Agronomy*, *43*(2), 277-293.

21. El-Said, R. (2018). Assessment of genetical parameters of yield and its attributes in bread wheat (*Triticum aestivum,* L.). *Journal of Agricultural Chemistry and Biotechnology*, *9*(10), 243-251.

22. El. E., & Marwa, M. (2018). Genetic behavior of some agronomic characters in three bread wheat crosses under different environmental conditions. *Alexandria Journal of Agricultural Sciences*, *63*(5), 313-325.
23. Eid, M. H. (2009). Estimation of heritability and genetic advance of yield traits in wheat (*Triticum aestivum* L.) under drought condition. *International Journal of Genetics and Molecular Biology*, *1*(7), 115-120.
24. Elmassry, E. L., Arab, S. A., & Al-Farouk, M. O. (2020). Combining Ability of Some Bread Wheat Genotypes for yield and its Components under Normal Watering and Water-Stress Conditions. *Journal of Plant Production*, *11*(12), 1517-1527.
25. Farhat, W.Z.E., Mohamed, Eman, N.M.M. (2018) Breeding for some agronomic and quality characters in bread wheat. *Journal of Plant Production, Mansoura University*, 9(3), 215-231.
26. Farshadfar, E., Rahmani, S., Jowkar, M. M., & Shabani, A. (2014). Estimation of genetic parameters and chromosomal localization of QTLs controlling agro-physiological indicators of drought tolerance in agropyron using wheat-agropyron disomic addition lines. *Australian Journal of Crop Science*, *8*(1), 133-139.
27. Fonseca, S., & Patterson, F. L. (1968). Hybrid vigor in a seven-parent diallel cross in common winter wheat (*Triticum aestivum* L.) 1. *Crop Science*, *8*(1), 85-88.
28. Gerema, G., Lule, D., Lemessa, F., & Mekonnen, T. (2020). Morphological characterization and genetic analysis in bread wheat germplasm: A combined study of heritability, genetic variance, genetic divergence and association of characters. *Agricultural Science & Technology (1313-8820)*, *12*(4).
29. Gomaa, M.A., El-Banna, M.N.M., Gadalla, A.M., Kandil, E.E., Ibrahim, A.R.H. (2014) Heterosis, combining ability and drought susceptibility index in some crosses of bread wheat (*Triticum aestivum* L.) under water stress conditions. *Middle East Journal of Agriculture Research*, 3(2), 338-345.
30. Griffing B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Science* 9, 463-493
31. Haleem, A., Hassan, G., Iqbal, A., Khan, F. U., Sajid, M., Ahmad, F., & Ilyas, M. (2022). Genetic variability and correlation analysis in F2 wheat populations. *Sarhad Journal of Agriculture*, *38*(2), 398-408.
32. Henderson CR. (1952). Specific and general combining ability. *In heterosis (Gowen, J.W. ed.), Iowa State College Press, Ames Iowa.*352-371.
33. Hayman BI. (1954). The theory and analysis of diallel crosses. *Genetics* 39 , 789-809.

34. Ishaaq, I., Farooq, M., Tahira, S., Maqbool, R., Barutçular, C., Yasir, M., & Rastogi, A. (2022). Exploration of Genetic Pattern of Phenological Traits in Wheat (*Triticum aestivum* L.) under Drought Stress. *Phyton-International Journal Of Experimental Botany*, *91*(12).
35. Jones DF. (1917). Dominance of linked factors as a means of accounting for heterosis. *Genetics* 2, 466-479
36. Kaur, S., Avinashe, H. A., Dubey, N., Kalubarme, S., & Kumar, M. (2019). Assessment of genetic variability and association analysis for yield and yield attributing traits in bread wheat (*Triticum aestivum* L.).*Plant Archives*, 19(1),1261-1267.
37. Kempthorne, O., & Curnow, R. N. (1961). The partial diallel cross. *Biometrics*, *17*(2), 229-250.
38. Khan, A. (2016). Performance of different bread wheat varieties for yield and yield attributes under diallel combinations. *Annals of Agrarian Science*, *14*(2), 25-34.
39. Khokhar, A.A., Nizamani, F.G., Rind, R.A., Nizamani, M.M., Khokhar, M.U., Shah, A., Nizamani, A.L., Rind, M. R. (2019) Combining ability estimates in 6 x 6 half diallel crosses of bread wheat (*Triticum aestivum* L.). *Pure and Applied Biology*, 8(3), 1980-1990.
40. Kumar, S., B. G., & Ahlawat, I. P. S. (2008). Integrated nutrient management in soybean (Glycine max)-wheat (*Triticum aestivum* L.) cropping system. *Indian Journal of Agronomy (India)*.
41. Kumar, J., Kumar, M., Kumar, A., Singh, S. K., & Singh, L. (2017). Estimation of genetic variability and heritability in bread wheat under abiotic stress. *International Journal of Pure and Applied Bioscience*, *5*(1), 156-163.
42. Kumar, N., Markar, S., & Kumar, V. (2014). Studies on heritability and genetic advance estimates in timely sown bread wheat (*Triticum aestivum* L.). *Bioscience Discovery*, *5*(1), 64-69.
43. Kumar, D., Panwar, I., Singh, V., Choudhary, R.R., Samita (2020) Heterosis studies using diallel analysis in bread wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies,* 8(4), 2353-2357.
44. Mathew, I., Shimelis, H., Mwadzingeni, L., Zengeni, R., Mutema, M., & Chaplot, V. (2018). Variance components and heritability of traits related to root: shoot biomass allocation and drought tolerance in wheat. *Euphytica*, *214*, 1-12.

45. Matzinger DF and Kempthorne O. (1956). The modified diallel table with partial inbreeding and interactions with environment. *Genetics* 41, 822-833
46. Mishra, A., & Liu, S. C. (2014). Changes in precipitation pattern and risk of drought over India in the context of global warming. *Journal of Geophysical Research: Atmospheres*, *119*(13), 7833-7841.
47. Mohamed, N. E. (2014). Genetic control for some traits using generation mean analysis in bread wheat (*Triticum aestivum* L.). *International Journal of Plant & Soil Science*, *3*(9), 1055-1068.
48. Muhammad, M., Rabbani, M.A., Shah, J., Zakiullah, A. A., and Ghazan, F. (2011). Genetic variability and correlation analysis of bread wheat (*Triticum aestivum* L.) accessions**.** *Pakistan Journal of Botany*. 43(6): 2717-2720.
49. Mwadzingeni, L., Shimelis, H., Dube, E., Laing, M. D., & Tsilo, T. J. (2016). Breeding wheat for drought tolerance: Progress and technologies. *Journal of Integrative Agriculture*, *15*(5), 935-943.
50. Mwadzingeni, L., Shimelis, H., & Tsilo, T. J. (2017). Variance components and heritability of yield and yield components of wheat under drought-stressed and non-stressed conditions. *Australian Journal of Crop Science*, *11*(11), 1425-1430.
51. Mwadzingeni, L., Shimelis, H., & Tsilo, T. J. (2018). Combining ability and gene action controlling yield and yield components in bread wheat (*Triticum aestivum* L.) under drought-stressed and non-stressed conditions. *Plant Breeding*, *137*(4), 502-513.
52. Naeem, M. K., Ahmed, M., Noreen, S., Shah, M. K. N., & Iqbal, M. S. (2015). Estimation of genetic components for plant growth and physiological traits of wheat (*Triticum aestivum* L.) under normal and stress conditions. *SAARC Journal of Agriculture*, *13*(1), 90-98.
53. Okechukwu, E. C., Agbo, C. U., Uguru, M. I., & Ogbonnaya, F. C. (2016). Germplasm evaluation of heat tolerance in bread wheat in Tel Hadya, Syria. *Chilean journal of agricultural research*, *76*(1), 9-17.
54. Ojo, G. O. S., Adedzwa, D. K., & Bello, L. L. (2007). Combining ability estimates and heterosis for grain yield and yield components in maize (*Zea mays* L.). *Journal of sustainable development in agriculture and environment*, *3*, 49-57.
55. Panhwar, N. A., Baloch, G. M., Soomro, Z. A., Sial, M. A., Panhwar, S. A., Afzal, A., & Lahori, A. H. (2022). 3. Evaluation of heterosis and its association among morpho-physiological traits of ten wheat genotypes under water stress. *Pure and Applied Biology (PAB)*, *11*(3), 709-724.

56. Qabil, N. (2017). Genetic analysis of yield and its attributes in wheat (*Triticum aestivum* L.) under normal irrigation and drought stress conditions. *Egyptian Journal of Agronomy*, 39(3), 337-356.
57. Rathore, B. M. S., Sud, R., Saxena, V., Rathore, L. S., Rathore, T. S., Subrahmanyam, V. G., & Roy, M. M. (2014, May). Drought conditions and management strategies in India. In *Country Workshop Report, Regional Workshop for Asia-Pacific, UN-Water Initiative on Capacity Development to Support National Drought Management Policies* (pp. 6-9).
58. Said, A. A. (2014). Generation mean analysis in wheat (*Triticum aestivum* L.) under drought stress conditions. *Annals of Agricultural Sciences*, *59*(2), 177-184.
59. Sallam, A., Hashad, M., Hamed, E. S., & Omara, M. (2015). Genetic variation of stem characters in wheat and their relation to kernel weight under drought and heat stresses. *Journal of crop science and biotechnology*, *18*, 137-146.
60. Salem, K. F., Alghuthaymi, M. A., Elabd, A. B., Elabsawy, E. A., & Mierah, H. H. (2022). Prediction of heterosis for agronomic traits in half-diallel cross of rice (*Oryza sativa* L.) under drought stress using microsatellite markers. *Plants*, *11*(12), 1532.
61. Semahegn, Y., Shimelis, H., Laing, M., & Mathew, I. (2021). Genetic variability and association of yield and yield components among bread wheat genotypes under drought-stressed conditions. *Australian Journal of Crop Science*, *15*(6), 863-870.
62. Shamuyarira, K. W., Shimelis, H., Tapera, T., & Tsilo, T. J. (2019). Genetic advancement of newly developed wheat populations under drought-stressed and non-stressed conditions. *Journal of Crop Science and Biotechnology*, *22*, 169-176.
63. Sharshar, A. M., & Genedy, M. S. (2020). Generation mean analysis for three bread wheat crosses under normal and water stress treatments. *Journal of Plant Production*, *11*(7), 617-626.
64. Shull GH. (1909). A pure line method of corn breeding. *American Breeders Association Report* 5, 51-59
65. Singh, D. R., Singh, P. K., Syamal, M. M., & Gautam, S. S. (2009). Studies on combining ability in okra. *Indian Journal of Horticulture*, *66*(2), 277-280.
66. Singh, L., Vats, P., Vishnoi, N., & Rathi, S. (2007). Heterotic effects, heritability, genetic advance and correlation coefficients among yield and quality attributes in 11 parent diallel crosses in wheat. *International Journal of plant science. (1)*, 75-79.

67. Singh, S. K., Singh, A., Kashyap, A. S., Singh, S., & Singh, C. P. (2008). Heterosis over better parent and mid parent under the Line x Tester design in lady finger (*Abelmoschus esculentus* L). *Flora and Fauna (Jhansi)*, *14*, 161-166.
68. Sprague GF and Tatum LA. (1942). General *vs* specific combining ability in single crosses of Corn. *Journal of American Society of Agronomy* 34, 923-932
69. Tadesse, W., Sanchez-Garcia, M., Assefa, S. G., Amri, A., Bishaw, Z., Ogbonnaya, F. C., & Baum, M. (2019). Genetic gains in wheat breeding and its role in feeding the world. *Crop Breeding, Genetics and Genomics*, *1*(1).
70. Taneva, K., Bozhanova, V., & Petrova, I. (2019). Variability, heritability and genetic advance of some grain quality traits and grain yield in durum wheat genotypes. *Bulgarian Journal of Agricultural Science*, *25*(2).
71. Thomas, T., Nayak, P. C., & Ghosh, N. C. (2015). Spatiotemporal analysis of drought characteristics in the Bundelkhand region of central India using the standardized precipitation index. *Journal of Hydrologic Engineering*, *20*(11), 05015004.
72. Thomas, N., Marker, S., Lal, G.M., Dayal, A. (2017) Study of heterosis for grain yield and its components in wheat (*Triticum aestivum* L.) over normal and heat stress condition. Journal of *Pharmacognosy and Phytochemistry*, 6(4), 824-830.
73. Yucel, B.F.S., Ozkan, H. (2011). Genetic analysis of some physical properties of bread wheat grain (*Triticum aestivum* L. em Thell). *Turk J Agric.* 525-535.
74. Zhang, X., Obringer, R., Wei, C., Chen, N., & Niyogi, D. (2017). Droughts in India from 1981 to 2013 and implications to wheat production. *Scientific reports*, *7*(1), 44552.
75. Zerga, K., Mekbib F., & Dessalegn T. (2016). Estimation of association among growth and yield related traits in Bread Wheat (*Triticum aestivum* L.) Genotypes at Gurage Zone, Ethiopia. *International Journal of Plant Breeding and Crop Science*, *3*(2), 123-134.

Publication

A comprehensive study of wheat genotypes for combining ability and heritability in drought tolerance. *Plant Science Today*. https://doi.org/10.14719/pst.3487.

Conferences

1. Participated in Oral presentation on the topic entitled "Hybrid yield analysis of wheat genotypes under drought stress conditions in Punjab" in the **International Conference on Bioengineering and Biosciences (ICBB-2022)** in association with the Society of Bioinformatics for Experimenting Scientists (Bioclues) on 18-19 November 2022 by the Department of Biotechnology, School of Bio-engineering and Biosciences at Lovely Professional University, Punjab.
2. Participated in Poster presentation on the topic entitled "GCA, SCA, and component analysis for the yield-related attributes in wheat" in **2nd International Conference on Plant Physiology and Biotechnology (ICPPB)** in association with Punjab State Council for Science and Technology on 20-21 April 2023 by the Division of Research and Department of Molecular and Genetic Engineering, School of Bio-engineering and Biosciences at Lovely Professional University, Punjab.