GENETIC ANALYSIS OF DROUGHT TOLERANCE IN CROSSES OF TWO ROW AND SIX ROW BARLEY (*Hordeum vulgare* L.)

काशी हिन्दू विश्वविद्यालय BANARAS HINDU UNIVERSITY

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy
in
Genetics and Plant Breeding

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ANNEXURE-F

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This is to certify that **Mr**. **Bornare Satish Santosh**, a bonafide research scholar of Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, has satisfactorily completed the course work, written and oral comprehensive examination and pre-submission seminar (Dated 16.07.2014) requirement which is a part of his Ph. D. programme.

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Genetic Analysis of Drought Tolerance in Crosses of Two Row and Six Row Barley (*Hordeum vulgare* L.)

By

Bornare Satish Santosh

Thesis submitted in partial fulfilment of the requirements for the degree of **"Doctor of Philosophy in Genetics and Plant Breeding"**, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

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Date :
***Place :** Varanasi*

(Bornare Satish Santosh)

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LIST OF SYMBOLS AND ABBREVIATIONS

%	percentage
°C	Degree centigrade
µg	microgram
µl	microliter
ANOVA	Analysis of Variance
BHU	Banaras Hindu University
bp	Base pair
CD	Critical difference
cm	centimeter
CRBD	Compact Family Randomized Block Design
CTAB	Cetyle trimethyle ammonium bromide
DNA	Deoxyribonucleic acid
dNTP	Deoxynucleoside triphosphate
e.g.	For example
EDTA	Ethylene diaminetetra acetic acid
et al.	Co-authors [et all ii]
etc.	*Et cetera*
F	Forward
FYM	Farm Yard Manure
g	gram
GA	Genetic advance
GCA and SCA	general and specific combining ability
h^2	Heritability
H_2O	Water
ha	hectare
i.e.	that is
MAS	Marker-assisted selection
mg	milligram
$MgCl_2$	Magnesium chloride
ml	mililiter
mM	milimolar
MSS	Mean sum of squares
N	Nitrogen
ng	nanogram

nm	nanometer
OD	Optical density
PCR	Polymerase chain reaction
pH	Potential of Hydrogen
PIC	Polymorphic Information Content
R	Reverse
rpm	Revolution per minute
SE	Standard error
SSR	Simple Sequence Repeat
TAE	Tris acetate EDTA
Taq	*Thermas aquaticus*
TE	Tris EDTA
Tris	Tris (hydroxymethyle) aminomethane
UPGMA	Un-weighted Pair Group Method with Arithmetic Mean
USA	United Sates of America
USDA	United States Department of Agriculture
UV	Ultra violet

PREFACE

The present investigation entitled **"Genetic analysis of drought tolerance in crosses of two row and six row barley (*Hordeum vulgare* L.)"** comprises of two parts. First part deals with the study the nature and magnitude of gene action controlling the inheritance of drought tolerance of yield and drought related characters under both rainfed and irrigated conditions and the best general and specific combiners for drought tolerance. Second part describes the selections of the high yielding drought tolerant transgressive sergeants using different drought parameters. This thesis is written for the award of doctoral degree in Genetics and Plant breeding under the supervision of **Dr. L. C. Prasad** and co-supervision of **Dr. J. P. Lal** (Professor, Deptt. of Genetics and Plant Breeding, Institute of Agricultural Sciences, BHU). Chapter wise presentation of the thesis is as follows:

Chapter 1 includes the introduction which provides a general background and an overview of the current situation of barley production in the country and worldwide. This chapter justifies the purpose for choosing this research topic, the yield losses due to drought, importance of barley as model crop to study drought tolerance/resistance, its genetic parameters, breeding techniques and objectives of the research work.

Chapter 2 includes review of literature which elaborates the available literature covering various aspects of variation, association and inheritance of drought tolerance/resistance components falling under the scope of the present study.

Chapter 3 includes the materials and methodology employed for carrying the research work and the details of treatments. The statistical analysis used in the present study has also been mentioned in this chapter.

In **Chapter 4** the experimental findings are presented which includes molecular diversity analysis for detecting parental polymorphism, general and specific combining ability effects of yield and drought related traits, components of genetic variance and extent of heterosis obtained for these traits, the estimates of the gene actions through generation mean analysis, isolation of transgressive sergeants and drought tolerant recombinants in F_2 generation.

In **Chapter 5** results obtained has been discussed and interpreted in the light of research work done in India and abroad.

In **Chapter 6** a brief description of the achievements obtained in the present investigation is given and a conclusion is drawn from this study with the hope that it will provide scope for further research and their application in management and developing cultivars to drought tolerance/resistance in barley through effective selection criteria for isolation of sergeants under moisture stress and non-stress condition.

Lastly bibliography includes the list of references in alphabetical order which has been consulted during the course of investigation and cited in the text.

Chapter I

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the leading food/feed crop ranks next only to wheat, rice and maize among the cereals cultivated worldwide (Bengtsson, 1992; Verma *et al*., 2010). Cultivated barley belongs to the tribe *Triticeae* a grass family of *Poaceae* which is the largest family of monocotyledonous plants. The genus *Hordeum* comprises 32 species and altogether 45 taxa (Bothmer *et al*., 1991). Barley has a wider ecological range than any other cereals and is widespread in temperate, subtropical and arctic areas, from sea level to heights of more than 4,500 meter in the Andes and Himalayas (Bothmer *et al*., 1995). It is grown in many areas where climatic conditions are unfavorable. Though its commercial value is less than that of wheat but it replaces the later in the dry regions in areas of too low and erratic rainfall, because of low input requirement and better adaptation, it survives easily under rainfed condition and known as poor men's crop (Verma *et al*., 2010). Barley covers nearly 30% of the world's total cereal production. European Union is the largest producer of barley in the world with a contribution of 42% followed by Russia (10%), France (9%), Germany (8%), Australia (5%) and Canada (8%). India does not find a place among the top 10 producing nations. Being a largest producer, European Union is also the largest consumer of barley, with a share of 40% of the total world consumption followed by Russia (12%), Canada (6%) and Saudi Arabia (5%). Although Ukraine is the third-largest producer, it ranks fifth in consumption because it exports majority of the produce (FAO 2012).

In India, barley is an important cereal crop cultivated in *Rabi* season, which occupied the place after wheat in both area and production. As an important *Rabi* cereal it is grown in the northern plains of India, comprising the states of Uttar Pradesh, Haryana, Rajasthan, Punjab, Madhya Pradesh, Himachal Pradesh and Uttarakhand. Low input demand and lower cost of cultivation are important factors for its preference by farmers, especially marginal and economically depressed farmers of these areas. Because of better grain development barley is grown under irrigated condition in the state of Haryana, Punjab, Rajasthan and parts of western Utter Pradesh for industrial utilization by the malting and brewing industries. The area and production of barley in the country has now more or less stabilized in the last few years with minor annual fluctuation, depending on the demand and price situation and cultivation of oil seed crop in rainfed conditions (Verma *et al*., 2010).

Though barley is primarily a rainfed crop it is also grown in irrigated condition on optimal management, consequently its productivity has been improving in India. However, India's share in global production is only 1.0% which is significantly very low. In India barley occupies nearly 0.76 million hectare and producing around 1.74 million tones grains (Kumar *et al*., 2014). Although, in India only selective states are producing barley; among them Rajasthan has a lion's share accounting for 40% of the total production followed by other major barley producers are Uttar Pradesh (31%), Madhya Pradesh (8%), Haryana (6%) and Punjab (5%) (www.carvy.comtrade.com/disclaimer.asp). During past decade both barley acreage and production are continuously declining because of change food habit of human being and also availability of substitute to the feed industries (corn) at the cheaper rate in market. However in recent years the area and production of barley has increased. This could be, to some extent, due to the effect of industrial as well as economic situation of the country. The main reason for the increased production is attributed to the crop's reliability to be grown even under fluctuating soil and climate. For the poor or marginal farmers this crop is an ideal one to be grown to begin with if they are new and other crops need experienced crop husbandry to grow them successfully. In India, some areas have abundant barley cultivation. Out of total 0.76 million hectares in the country under barley crops, only about 20% is taken as irrigated while the remaining 80% is cultivated as rainfed. The late sown barley has given better economic return than the late sown crop wheat.

The near east i.e. Java Island is considered to be the origin of common barley. Barley together with emmer wheat was the first cereal to be domesticated in the Middle East, at least 9000 year ago. The first archaeological material of barley was two rowed barley which closely resemble with some races of wild barley, i.e.

Hordeum spontaneum. This wild species crosses readily with cultivated barley and its progenitor species of *H. vulgare*. Therefore all the cultivated forms of barley are thought to have originated from a wild species *Hordeum spontaneum*, a species very similar to present day two rowed barley. Archaeologist also supports the two-row species as progenitor of six-rowed barley (*Hordeum vulgare* L.). *Hordeum vulgare* is the only cultivated species which has two distinct phenotype forms, *viz*., two-rowed and six-rowed type based on ear morphology. Initially these two forms were classified as two separate but now these have been grouped into single species *Hordeum vulgare.* These two have same chromosome number (2n=24), inter-cross freely and produce fertile hybrids (Poehlman, 1987). Barley spikelets are arranged in triplets which alternate along the rachis. In wild barley, only the central spikelet is fertile, while the other two are unfertile. This condition is retained in certain cultivars known as two-row barley. A pair of mutations (one dominant and the other recessive) result in fertile lateral spikelets; this produces six-row barley. A mutation in one gene, *vrs1*, is responsible for the transition from two-row to six-row barley. Two-row barley has lower protein content than six-row barley and thus has more fermentable sugar. Due to destined merits of both the types, 6 genotypes from two rows and 4 genotypes from six rows were taken for making the crosses in the present study.

Barley must have been introduced in India during historic times and was continued primarily, as human food in the form of *Chapatti* and *Sattu* but due to alternate use of barley in the field of brewing and medicinal industry, it is considered as highly needed crop of present era. Apart from human consumption as food and drinks, barley foods are also considered as *traditional medicines* in curing human diseases. The effectiveness of barley b-glucans in barley food products in lowering blood cholesterol (Fadel *et al*., 1987; Behall *et al*., 2004) and glycemic index (Wood *et al*., 1990; Braaten *et al*., 1991; Cavallero *et al*., 2002) has been reported in numerous publications and is widely accepted (Pins and Kaur, 2006). Barley is a rich source of tocols, including tocopherols and tocotrienols, which are known to reduce serum lethal density level cholesterol through their antioxidant action (Qureshi *et al*., 1986 and 1991). Whole barley grain consists of about 65-68% starch, 10-17% protein, 4-9% b-glucan, 2–3% free lipids and 1.5-2.5% minerals (Czuchajowska *et* *al*., 1998; Izydorczyk *et al*., 2000; Quinde *et al*., 2004). Total dietary fiber ranges from 11 to 34% and soluble dietary fiber from 3 to 20% (Fastnaught, 2001). Hulless or de-hulled barley grain contains 11-20% total dietary fiber, 11-14% insoluble dietary fiber and 3-10% soluble dietary fiber (Marlett, 1991; Fastnaught *et al*., 1996; Marconi *et al*., 2000; Fastnaught, 2001; Virkki *et al*., 2004).

Barley is a short-season, early maturing, diploid and self-pollinating crop and is an ideal model plant for genetic study of drought and salinity tolerance. Drought is the single most important factor limiting yield. Yet, compared to other cereals, barley is well adapted due to better water-use efficiency and mechanisms of drought escape, avoidance and tolerance. Ceccarelli *et al*. (1998) demonstrated that the most effective way to improve productivity of barley grown in drought conditions is to use locally adapted germplasm and select in the target environment(s). Although breeding for drought resistance based on direct selection for grain yield in the target environment (empirical or pragmatic breeding) appears to be the most obvious solution. This approach faces two major problems; first one, the precision of the yield trials conducted under drought conditions, and secondly, the existence of several target environments, each characterized by its own specific type of drought and combination of stress, (Ceccarelli and Grando, 2002). Breeding for drought resistance based on putative traits (traits associated with drought resistance, but easier to select for than grain yield) has been very popular, but the progress is still slow. However, most of traits were controlled by multiple genes and environments played an important role in the expression of specific traits. In several studies, it has been shown that the developmental genes are key factors in the determination of yield potential under drought condition (Teulat *et al*., 2001; Baum *et al*., 2003; Forster *et al*., 2004). These genes include photoperiod response, basic vegetative period, earliness and vernalization.

Proper choice of parents on the basis of their combining ability status for putative drought tolerant attributes as well as productive traits and selection in typical target environment will help in combining complex traits, such as, productivity and drought tolerance (Hanamaratti *et al*., 2004). The concept of combining ability helps the breeder to determine the nature of gene action involved in the expression of quantitative traits of economic importance. The choice of suitable breeding method for the improvement of drought tolerance traits primarily depends on the relative importance of GCA and SCA variances. A hybrid is commercially valuable only when it exhibits significantly high standard heterosis over the best locally adapted variety or hybrid. Apart from high vigor and yield, the hybrids can be a potential genetic source for better root system with higher efficiency to absorb moisture effectively for tolerating drought condition. Existence of heterosis for desired traits will be a boon to drought tolerance breeding since most of the hybrids developed so far lack tolerance to abiotic stresses. The generation mean analysis is one of most appropriate methods of genetic analysis for quantitative traits (Eshghi and Akhundova, 2010). In this method, epistatic effects as well as additive and dominance effects can be estimated. Besides gene effects, breeders would also like to know how much of the variation in a crop is genetic and to what extent this variation is transferring generation after generation. Because efficiency of selection mainly depends on additive genetic action, influence of the environment and interaction between genotype and environment as well.

Although, barley workers continuously working on identifying barley varieties tolerant to drought and the traits associated with drought tolerance, the pace is low (Acevedo and Ceccarelli 1989; Ceccarelli and Grando,1996; Grando *et al*., 2001). Yield and yield stability under drought are still considered as the most important parameters for drought tolerance (Li *et al*., 2007). Along with yield traits, certain physiological or biochemical traits, such as proline content, osmotic adjustment capacity, stomatal conductance, plant water status, water-soluble carbohydrates growth habit, early growth vigor, earliness, plant height under drought, long peduncle and short grain filling duration are the important characteristics consistently associated with higher yield under drought (Ceccarelli *et al*., 2004; Li *et al*., 2007). Among them proline is perhaps the most widely distributed compatible osmolyte (Delauney and Verma 1993; Ueda *et al*., 2001; Chen *et al*., 2007; Majid *et al*., 2012). Other traits, stomatal conductance (Farquhar and Sharkey 1982; Sinclair, 2000; Jiang *et al*., 2006; Robredo *et al*., 2007) and osmotic adjustment (Morgan 1984;

Blum 1988; Zhu *et al*. 1997; Serraj and Sinclair 2002) are related to survival under severe drought. Therefore due consideration should be given to these traits along with yield trait during selection of drought tolerant genotypes.

An improvement of these traits in cultivated plants by deriving segregants superior to parents, which could be developed as cultivars, is a main goal in breeding of self-pollinated crops, including barley. Breeders of self-pollinated crops are still looking for methods of effective choice of parental genotypes (Kuczynska *et al*. 2007). Transgressive segregation may be a key to the improvement of cultivated plants. An attempt is, therefore, made in the present study to select the drought tolerant transgressive segregants on the basis of grain yield and proline content.

With these points in view, the present investigation entitled **"Genetic analysis of drought tolerance in crosses of two row and six row barley (*Hordeum vulgare* L.)"** was undertaken with the following objectives.

1. To study the nature and magnitude of gene action controlling the inheritance of drought tolerance, yield and yield contributing characters in rainfed condition.
2. To find out the best general and specific combiners for drought tolerance.
3. To select the high yielding drought tolerant transgressive segregants using different drought parameters.

Chapter II

REVIEW OF LITERATURE

Plant breeding is essentially an opportunity to select the best plants within a variable population as a potential cultivar. In other words, plant breeding is a selection made possible by the existence of variability. The variation exploited in most breeding programmes is derived from naturally occurring variants and the wild relatives of main crop species as well as artificially synthesized variants or strains constitutes its germplasm. Variability is the basic requirement for successful genetic improvement in a crop. Barley genotypes possess tremendous variability in respect of morphological, physiological and yield and its contributing traits. The large spectrum of genetic variability in segregating populations depends on the extent of genetic diversity among genotypes, offer better scope for selection.

Success of any crop improvement programme through recombination breeding depends largely on genetic constitution of parent and behaviour of the traits. Selection of suitable parents in hybridization programme, from available genetic diversity is an important step in the development of a new variety in any crop species and it plays a vital role in planning a successful crop improvement programme.

Various biometrical procedures are used by plant breeders for estimation of genetic value of parents and evaluation of varieties and hybrids in terms of their genetic makeup in different adverse conditions. Literature in respect of combining ability and gene action, heterosis and inbreeding depression and drought tolerance/ resistance for various yield and drought related traits have been reviewed and presented in this chapter as follows

2.1 Combining ability and gene effects

Budak (2000) reported that GCA was significant for grain yield, plant height and 1000 grain weight whereas SCA was significant for plant height in the F_1 generation in barley.

Yawen and Liangzheng (2001) observed plant height showed positive SCA for 24 combinations, effective grain number for 24 combinations, grain weight per panicle for 26 combinations and 1000 kernel weight for 20 combinations in barley. They concluded that the varieties with low GCA such as Diamond and Karan 15, Yunnan Ziguangmangerlin and 8640, etc. showed high SCA in cross estimations.

Bhatnagar *et al.* (2002) reported that the proportion $(H1/D)^{1/2}$ was found to be near unity for days to maturity, plant height and ear length in F_1, indicating complete dominance while for rest of the characters in F_1 and for all traits in F_2, the value was above one, suggesting either over dominance or epistasis in the expression of the characters of barley.

Sharma *et al.* (2002) had undertaken combining ability analysis in 10 x 10 half-diallel progenies (F_1 and F_2) for grain yield and its component characters of barley. The GCA and SCA components of variance were significant for all the traits. The GCA: SCA ratio revealed predominance of non-additive gene effects for the traits studied. Among the parents tested RD 2035, RD 2052, RD 2503, RD 2508 and BL 2 were the best general combiners for grain yield and average to high combiners for other important traits.

Yadav *et al.* (2002) observed additive component was predominant for plant height, grains per spike and protein content where as dominant genetic variance was significant for productive tillers per plant, spike length, grain yield per plant, 1000 kernel weight, husk content and malt yield of barley. Over dominance was observed for all the traits in both the generations except for grains/spike and protein content where partial dominance was important.

El bawab *et al*. (2003) reported additive gene action was predominant which was conferring the results of GCA and GCA/SCA ratios (exceeded the unity) in barley.

Sharma *et al*. (2003) studied combining ability analysis in six-rowed barley involving 10 diverse parents and their 45 F_1's and F_2's progenies indicated significant differences among the parents for GCA and crosses for SCA for all the characters studied. The GCA: SCA ratio showed that among the two types of genetic effects, the non-additive gene effects were more important in comparison to additive gene effects in controlling the inheritance of the characters under study. Among the parents RD 2052, RD 2503 and BL 2 were the best general combiners for grain yield and average to high combiners for other important traits.

Baghizadeh *et al.* (2004) evaluated heritability and gene action for some of the important quantitative traits in barley and indicated that the dominance gene effects were the most important for inheritance of all the traits studied and average broad sense heritability estimates were between 55 and 89%.

Kularia and Sharma (2005) reported that the dominance component was significant and greater in magnitude than the additive component for most of the traits in most of the barley crosses (RD 2503 x BL 2, Rajikiran x IBVT 12 and RD 2508 x RD 2052). Additive x additive and dominance x dominance interactions were significant for days to heading and days to maturity in RD 2503 x BL 2; in cross RD 2508 x RD 2052 for plant height, number of effective tillers per plant, harvest index and grain yield per plant; and in cross Rajkiran x IBVT 12 for days to heading, days to maturity, number of effective tillers per plant and grain yield per plant.

Ved Prakash and Verma (2006) observed over dominance for plant height in BL-2 x RD 2433 and partial dominance in RD 2407 x RD 2433 in barley. Heritability and genetic advance were low suggesting complex inheritance and non-additive gene action.

Kakani *et al.* (2007) revealed that the GCA: SCA ratio showed preponderance of the non-additive gene action for the characters namely, days to maturity, plant height, effective tiller per plant, biological yield per plant, grain yield per plant and harvest index of barley. However, additive gene action was more pronounced for day to heading and test weight. Among the parents RD 2508, RD 2552 and RD 2503 were the best general combiners for grain yield and average to high combiners for other important traits.

Khan *et al.* (2007) observed additive gene effects were operating for plant height, biomass per plant, number of grains per spike and grain yield per plant while number of tillers per plant and 1000 grain weight were controlled by non-additive gene effects in wheat. The genotypes of Uqab 2000 proved to be good general combiner for grain yield, 1000-grain weight, biomass per plant, number of tillers per plant and plant height.

Madic *et al.* (2007) emphasized highly significant differences for the general (GCA) and specific (SCA) combining abilities in the F_1 generation of barley showed that the grain weight per plant in these investigations was dependent on genes with additive and non-additive (dominant) effects.

Singh *et al*. (2007) carried out combining ability analysis and gene action studies involving 8 lines and 5 testers in barely for grain yield and its components and reported that the relative estimates of variance due to SCA were higher than variance due to GCA for all the traits studied except days to flowering indicating the predominance of non-additive gene action.

Verma *et al.* (2007) conducted a study on combining ability effects through line x tester analysis under normal fertile and saline sodic soil environments in barley. The results indicated the predominance of non- additive gene action for all the traits. The line Kedar and tester K-560 in normal fertile soil and tester Lakhan in saline sodic soil while RD-2552, Narendra Jau-4 and NDB-1173 under both the environments proved good general combiners for seed yield and quality components characters.

Eshghi and Akhundova (2009) carried out generation mean and variance analysis on six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) derived from the barley cross ICNBF93-369 x ICNBF-582 and SB91925 x ICB-102607 to complement the genetic information obtained from the diallel analysis. Wr/Vr graph in diallel analysis and average degree of dominance together with narrow sense heritability values in both the experiments which revealed additive gene effects for plant height, number of tillers and days to maturity and over-dominance gene action for number of grains per spike.

Pal and Kumar (2009) revealed the significant role of additive genetic component (D) for the inheritance of days to 50% heading, plant height and spikelets per ear in barley. The non additive component (H1) was found to be important for the genetic control of all the traits except for days to 50% heading and tillers per plant. However, the relative magnitude of dominant component (H1) was higher as compared to additive component (D) in all the traits indicating the preponderance of dominant gene effects in controlling the inheritance of these traits.

Rabbani *et al.* (2009) based on the wr/vr graphic representation showed that traits like flag leaf area, fertile tillers per plant, 1000-grain weight and grain yield per plant were controlled by over-dominance type of gene action under irrigated and rainfed conditions in wheat. While spike length exhibited over-dominance type of gene action under irrigated conditions and additive type of gene action under rainfed conditions.

Eshghi ***et al*****.** (2010) carried out generation mean and variance analyses in barley and reported that both additive and dominance effects were important for most of the traits evaluated but dominance and non-allelic interaction had a more pronounced effect for number of grains per spikes in drought and 1000 grain weight and grain yield on both the environments.

El-aty (2011) indicated presence of non-allelic interaction for all the studied traits in all the crosses under study in barley; the additive effect was more important and greater than the dominance effect for most of the traits. Among the epistatic components, dominance × dominance was greater in the magnitudes than additive × additive and additive × dominance in the most studied traits.

Singh *et al.* (2011) reported that GCA and SCA variances were significant for all the traits except number of spikes per plant at SCA level in barley. The GCA variances were higher than SCA variances in respect of all the traits except grain yield per plant where both GCA and SCA were of same in order. The additive gene effects were generally predominant whereas dominance and over dominance gene effects were equally important for grain yield per plant.

Jain and Sastry (2012) observed the mean square due to GCA and SCA were significant for most of the traits which indicates the presence of both additive and non additive gene effects for controlling the expression of yield and yield contributing characters in wheat. The σ2 GCA / σ2 SCA ratio suggested that the presence of non additive gene action was predominant for most of the characters including grain yield.

Singh *et al.* (2012) reported that on the basis of GCA and SCA effects, 3 parents (K 7903, K 9465 and HUW 234) and 14 cross combinations (5 top crosses namely HD 2733 × K 7903, HUW 234 × K 9423, HD 2285 × K 2021, HUW 234 × K 2021 and K 9423 × K 2021) were found good general and specific combiners for higher grain yield and also for various yield contributing traits, respectively in wheat.

Desale and Mehta (2013) revealed that the mean squares due to both GCA and SCA were significant for all traits in wheat indicating both additive and non-additive genetic variances played a vital role in the inheritance of all these traits. The ratio between GCA and SCA variance was less than unity for all the traits which indicated that non-additive component play relatively greater role in the inheritance of all eight traits. On the basis of GCA, SCA effects and *per se* performance, parents HI-1544 for all the traits except biological yield per plant and reducing sugar and HW-5018 for all the traits except biological yield per plant and chlorophyll content and two crosses namely HW-5018 x HI-1544 and RAJ-4136 x UAS-281 for four traits were found as good general and specific combiners, respectively.

Fellahi *et al.* (2013) revealed that low $\sigma 2$ GCA/$\sigma 2$ SCA ratios and low to intermediate estimates of h^2_{ns} supported the involvement of both additive and non additive gene effects in wheat. The preponderance of non-additive type of gene actions clearly indicated that selection of superior plants should be postponed to later generation.

Pawar and Singh (2013) revealed that GCA and SCA variance were highly significant for all the traits studied in barley. Four parents JB1, PL751, JB58 and RD2787 were found to be good combiners for most of the characters and can be used in the future breeding program. Cross combinations JB × HUB208, JB58 × HUB208, JB1 × Bh933 and JB1 × JB58 exhibited high significant positive SCA effects for most of the traits and identified as superior crosses.

Potla *et al.* (2013) studied combining ability analysis in barley and reported significant differences among the parents for GCA, among the crosses for SCA for all the quantitative traits. Among the parents, tester namely RD-2508 and lines IBON-65, IBON-18, Beecher, Rihane, Moroc-9-75, 11th HBSN-146 and HUB-174 were good general combiners for grain yield and its component traits.

Raikwar (2013) examined genetic architecture of quantitative and qualitative traits in barley under saline sodic soil using generation mean analysis of the five crosses, results of which revealed that magnitude of dominance (*h*) effects was higher than additive (*d*) effects indicating the preponderance of dominance (*h*) effects over the additive effects. It is obvious that non fixable gene effects (*h*), (*j*) and (*l*) were higher than the fixable (*d*) (*i*) in all the crosses in all the characters indicating greater role of non-additive effects in the inheritance of all the characters.

Saad *et al.* (2013) working with barley reported that both general (GCA) and specific (SCA) combining ability variances were significant for most studied traits under both irrigation regimes indicating the importance of additive and non-additive genetic variances in determining the performance of these traits.

Varzaru and Ciulca (2013) examined the the overdominance effects have been found for the combinations where the parental forms did not differ in terms of the grains number/spike, while in the combinations where there were larger differences between parental forms, the inheritance of this trait was controlled by partial dominance effects. The inheritance of TGW for most combinations (87 %) was controlled by overdominance effects, associated with an increase in this trait.

Madic *et al.* (2014) observed that analysis of variance of combining abilities showed significant differences for GCA and SCA in the F_1 generation of barley suggesting additive and non-additive gene action. The GCA/SCA ratio in F_1 indicated the prevalence of the additive component of genetic variance for spike length, grain weight per spike and spike harvest index. By contrast the SCA variance for grain weight per spike was higher than the GCA variance indicating the dominance of non-additive gene action.

Raikwar *et al*. (2014) studied nature and magnitude of gene effects for yield and its component traits in barley using generation mean analysis in five crosses. In general, magnitude of dominance effect (h) showed a greater value than additive effect (*d*) in all the traits. It is obvious that non-fixable gene effects (*h*), (*j*) and (*l*) were higher than the fixable (*d*) and (*i*) in all the crosses in all the characters indicating the greater role of non-additive effects in the inheritance of all the characters. The study revealed the importance of non-additive type of gene action for most of the traits thereby suggesting that selection at later segregating generation could provide better results.

2.2 Heterosis and inbreeding depression

Yılmaz and Konak (2000) reported highest positive heterotic values 25.00% for seedling emergence, 26.53% for root length, 66.27% for shoot length to root length ratio, 9.39% for spike length, 26.69% for number of spikelets per spike, 50.11% for thousand grain weight and 33.12% for single spike yield in barley. The highest positive heterobeltiosis values were 50.98% for shoot length to root length ratio and 46.58% for thousand grain weight, respectively.

Yawen and Liangzheng (2001) crossed 10 genotypes of barley in half diallel fashion and 45 crosses and their 10 parents were screened in a 3-replicated randomized block design The positive and significant heterosis for effective grain number was observed in the 27 combinations, for the grain weight per panicle in 37 combinations and for the 1000-kernel weight in 42 combinations. Crosses between Yunnan Ziguangmangerlin and American, Canadian, Mexican, Hubei of China expressed a lot of heterosis.

El-bawab *et al*. (2003) revealed that the cross P_1xP_5 was the best cross as it expressed significant negative heterotic effect for heading date and showed useful heterosis for yield and yield components of barley. Also, useful heterosis was obtained from 6 hybrids for plant height, 15 for spike length, 13 for number of spikelets per panicle, 14 for number of grains per spike, 12 for spike grain weight, 10 for biological yield per plant, 12 for grain yield per plant and 6 for 1000 grain weight. Hence, these crosses can be used in breeding for earliness and the other studied characters.

Rugen *et al*. (2004) showed that the mid parent heterosis often existed and the occurrence rates of positively and negatively significant mid parent heterosis were 46% and 12%, respectively. On the other hand, the occurrence rate of the significant heterobeltiosis was 28% on average, ranging from 0% (Plant height and Kernels on main spike) to 79% (Internode length below spike), varied with the traits. The crosses of 3 x 10 and 6 x 8 had strong heterosis, and they belong to the combinations of 6 row x 6 row types and 2 row x 2 row types of barley, respectively. It seems that the hybrid with strong heterosis could be easier to find in the combinations of 6 row x 6 row or 2 row x 2 row barley types than that of 6 row x 2 row or 2 row x 6 row barley types.

Kularia and Sharma (2006) reported that the range of heterosis was quite wide except for days to heading and plant height indicating that sufficient amount of genetic variability was present in the parent material of barley. Maximum heterobeltiosis (-2.21) in desirable direction was recorded in the cross RD 2508 x RD 2052 for days to heading with significant inbreeding depression. All the three crosses showed positive and significant heterobeltiosis (12.57 to 33.54 %) and inbreeding depression (-8.41 to 24.07%) for 1000-grain weight. Two crosses out of three expressed significant positive heterobeltiosis for biological yield per plant. The negative inbreeding depression was depicted by the cross Rajkiran x IBVT 12 indicating more biological yield in segregating generation.

El-aty (2011) found positive heterotic effects relative to the mid-parent for most of the traits in the five crosses of barley, except for heading and maturity dates that showed negative heterotic effects. Also positive heterotic effects relative to the better parent were found for the most of crosses. Heritability estimates in narrow sense were low to moderate for the studied characters in all the crosses which ranged from 16.37% for spike length in the fifth cross to 66%for days to heading in the second cross.

Koumber and El-gammaal (2012) reported highly significant heterotic values in positive direction for all characters except for plant height and 1000 grain yield in the first cross, spike length in the second cross and plant height, number of grains per spike and number of spikes per plant in the third cross of wheat. Over dominance for all characters except plant height and 1000-grain weight in the first cross, spike length in the second cross and number of grains per spike in the third cross were detected. Inbreeding depression was obtained in two out of three crosses for spike length, number of grains per spike, number of spikes per plant, 1000-grain weight and grain yield per plant and in one out of the three crosses for plant height.

Singh *et al*. (2011) studied the magnitude of heterosis and combining ability in six rowed barley was using 5 x 5 diallel systems for plant height, number of spikes per plant, 1000-grain weight and grain yield per plant. Positive heterosis was observed for all the traits except 1000-grain weight. Over dominance was observed only for grain yield per plant The heterosis and over dominance for grain yield per plant were positive in all the crosses except K 560 x K 635 where it showed partial dominance. For 1000-grain weight negative heterosis was observed in all the crosses except BH 495 x PL 508 for plant height positive heterosis was observed in eight cases and over dominance for three.

Potla *et al*. (2013) recorded that cross IBON-65 × RD-2508 showed highest magnitude of economic heterosis over the best standard check K- 603 for grain yield per plant in barley.

Saad *et al*. (2013) observed some crosses showed significant desirable heterobeltiosis for all the studied traits under both irrigation regimes. The high positive heterobeltiosis for grain yield per plant was associated with high positive heterobeltiosis for number of spikelet per panicle and 1000 grain weight for barley crosses Giza 126 X Giza 2000 and Giza 130 X Giza 131 under stress and non-stress conditions, respectively.

2.3 Drought tolerance/ resistance

Samarah (2005) conducted a greenhouse experiment to study the effect of drought stress on grain growth and yield of barley. Grain dry weight for severe drought stress plants reached a maximum value earlier than grains from mild drought stress and well-watered plants indicating that grains from severe drought stress plants had a higher growth rate than those of mild drought stress and well-watered plants. Drought stressed plants had shorter duration of grain filling than well-watered plants. Drought stress treatments reduced grain yield by reducing the number of tillers, spikes and grains per plant and individual grain weight.

Li *et al*. (2006) revealed that the components of the photosynthetic apparatus could be damaged significantly in drought sensitive genotypes while drought tolerant genotypes were relatively less affected. On the other hand the values of chlorophyll content in drought tolerance genotypes were significantly higher than those in drought sensitive genotypes under drought stress. It was concluded that chlorophyll content could be considered as reliable indicators in screening barley germplasm for drought tolerance.

Ali *et al*. (2009) studied six parental barley genotypes differed in their tolerant potentiality against drought and their 15 F_1's hybrids were assessed under the two conditions to detect their drought tolerance. Diallel analyses were conducted to estimate the genetic components and heritability. The results showed that mean squares of genotypes, parents and crosses were significant to highly significant for all the traits under non stress and stress conditions.

Guo *et al*. (2009) monitored the changes in gene expression at the transcriptional level in barley leaves during the reproductive stage under drought conditions, the 22K Affymetrix Barley 1 microarray was used to screen two drought-tolerant barley genotypes, Martin and Hordeum spontaneum 41-1 (HS41-1) and one drought-sensitive genotype Moroc9-75. Seventeen genes were expressed exclusively in the two drought-tolerant genotypes under drought stress and concluded that their encoded proteins may play significant roles in enhancing drought tolerance through controlling stomatal closure via carbon metabolism (NADP malic enzyme, NADP-ME, and pyruvate dehydrogenase, PDH), synthesizing the osmoprotectant glycine-betaine (C-4 sterol methyl oxidase, CSMO), generating protectants against reactive-oxygen species scavenging (aldehyde dehydrogenase, ALDH, ascorbate-dependent oxidoreductase, ADOR), and stabilizing membranes and proteins (heat-shock protein 17.8, HSP17.8, and dehydrin 3, DHN3).

Lal *et al*. (2009) reported that the barley segregants selected on the basis of drought parameters Yd, Yp, GM and S values performed better than others in cross RD 2552 x K 560.

Eshghi *et al*. (2010) suggested that both additive and dominance effects were important for most of traits evaluated in barely but dominance and non allelic interaction had a pronounced effects for number of grains per spike in drought and 1000 grain weight and grain yield in both moisture stress and moisture non-stress environments.

Eviatar and Chen (2010) reported that rainfed genotypes showed lower stomatal conductance than irrigated genotypes with or without drought treatment. A higher capacity of osmotic adjustment was found in rainfed genotypes than irrigated barley genotypes.

Gonzalez and Ayerbe (2010) reported that the breeding lines studied under the water stress conditions showed a greater mean epicuticular wax load than the commercial varieties while the residual transpiration rate was greater in these varieties than in the breeding lines. The greater epicuticular wax load of the breeding lines favoured their tolerance of drought improving their yields over those of the commercial varieties.

Gonzalez *et al*. (2010) examined the effect of drought on different gas exchange variables, i.e. net photosynthesis, stomatal conductance and leaf chlorophyll concentration and the relationship of these variables with yield in 12 barley genotypes grown under irrigated and terminal drought conditions. A significant correlation was seen between these physiological traits and yield. These results suggest a potential indirect selection of physiological characteristics in these breeding lines that allow greater tolerance to drought.

Lakew *et al*. (2010) assessed the importance of the wild progenitor of cultivated barley in contributing developmental and yield related traits associated with drought tolerance and therefore its usefulness in breeding for improved adaptation to drought stress conditions. Traits such as peduncle length, peduncle extrusion and plant height were positively correlated with grain yield in the dry environments. Differences in phenology were small and not significantly correlated with differences in grain yield under stress. Performances at the three highest yielding environments were much more closely correlated than those at the four stress environments.

Vaezi *et al*. (2010) examined that under drought stress condition, 1000 grain weight, grains per spike, relative water content and stay-green correlated positively with yield per plant of barley while under both moisture stress and moisture non-stress conditions the correlation of yield and plant height was lower than other correlations.

Akcura *et al*. (2011) evaluated thirty six bread wheat genotypes under both moisture stress (rainfed) and non stress (irrigated) conditions. Nine drought tolerance indices including yield stability index (YSI), yield index (YI), superiority index (Pi), stress tolerance index (STI), geometric mean productivity (GMP), stress susceptibility index (SSI), mean productivity (MP), stress tolerance (TOL), harmonic mean (HM) and linear regression coefficient (bi) were calculated. The indices were adjusted based on grain yield under drought condition (Ys) and normal conditions (Yp). SSI is suggested as useful indicator for wheat breeding where the stress is severe while MP, GMP, TOL HM and STI are suggested if the stress is less severe.

Lal *et al*. (2011) reported that the component traits, such as, tillers per plant, grains per spike, seed weight and harvest index singly or in combinations in general, appears to be most important towards enhancing seed yield of transgressive segregants derived from different crosses made in barley under both rainfed and irrigated environments.

Khokhar *et al*. (2012) evaluated twelve barley genotypes based on different selection methods under drought and irrigated conditions. The results of a correlation matrix revealed highly significant associations between grain yield (Yp) and mean productivity (MP), stress tolerance index (STI), geometric mean productivity (GMP) and yield index (YI) under irrigated conditions while the mean productivity (MP), yield stability index (YSI), stress tolerance index (STI), geometric mean productivity (GMP) and yield index (YI) had a high response under stressed condition. Based on a principal component analysis, geometric mean productivity (GMP), mean productivity (MP) and stress tolerance index (STI) were considered to be the best parameters for selection of drought-tolerant genotypes.

Bahari *et al*. (2013) reported the application of sensitivity and stress tolerance indices such as MP, GMP, TOL, SSI and STI on grain yield of wheat showed that among the 14 genotypes, genotype 10 was the most desirable. Also, with respect to a meaningful and positive correlation between biomass weight at anthesis stage and grain weight in spike in both normal irrigation and stressed conditions after the anthesis stage, it is recommended that the use of grain weight in spike at anthesis time in breeding programs should be considered.

Dehbalaei *et al*. (2013) studied 14 drought tolerance indices including stress tolerance index (STI), stress susceptibility index (SSI), tolerance index (TOL), harmonic mean (HAM), geometric mean production (GMP), mean production (MP), yield index (YI), yield stability index (YSI), drought resistance index (DI), abiotic tolerance index (ATI), stress non-stress product index (SNPI), modified stress tolerance (MSTI), and stress susceptibility percentage index (SSPI). These were calculated based on grain yield under drought (Ys) and irrigated conditions (Yp). Grain yield in stress (Ys) condition were significantly and positively correlated with Yp, STI, GMP, MP, HAM, YI, SNPI, DI, K_1STI and K_2STI and negatively correlated with SSI. Grain yield in non-stress (Yp) condition were significantly and positively correlated with STI, GMP, MP, HM, YI, SSPI, SNPI, ATI, K_1, K_2 and TOL. Grain yield in stress condition showed negatively correlated with SSI. Results of this study showed that these indices of stress tolerance/resistance such as K_1STI, K_2STI, SSPI, ATI, SNPI, and DI can be used as the most suitable indicators for screening drought tolerant cultivars.

Rad *et al*. (2013) studied drought stress indices (STI and GMP) and observed that the cross Irena × Chamran was the most tolerant genotype of wheat under the study. Correlation coefficients between two drought stress indices and the third factor from the factor analysis, which influenced relative water content and plant yield, were positive and significant. Thus, relative water content may be a good criterion for selection of tolerant genotypes with higher yields in breeding programmes.

Chapter III

MATERIALS AND METHODS

The materials and techniques applied during the course of investigation are presented in this chapter with details of sets of experiments followed by statistical procedures used as per plan of work.

3.1 Experimental material and other details

3.1.1 Experimental site

The experiments were conducted during the *Rabi* (winter) season of 2010-2011, 2011-12 and 2012-13 at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The experimental area occupied was quite uniform in respect of topography and fertility. The soil of experimental site is sandy loam having 0.03 % carbon approximately.

3.1.2 Climate and Weather

Geographically, Varanasi is situated at 25.28^0N latitude and 82.95^0E longitude in North Gangetic plain in eastern part of Uttar Pradesh (India). Varanasi experiences a humid subtropical climate with large variations between summer and winter temperatures. The dry summer starts in April and lasts until June followed by the monsoon season from July to September. The temperature ranges between 22 and 46 °C in the summers. Winters in Varanasi experience very large diurnal variations with warm days and downright cold nights. The average annual rainfall is 1100 mm (44 inch). The meteorological data during barley crop growth period from December to April 2011-12 and 2012-13 have been given in appendix.

3.1.3 Experimental material

The experimental materials consist of the 6 lines and 4 testers, the details of which are as follows.

Table 3.1: Details of selected barley genotypes.

S.No.	Name of Lines/ Testers	Pedigree	Sources	Origin
	Lines (two row)			
1.	BCU-4910	29th IBON 9	CIMMYT	Exotic
2.	BCU-4922	29th IBON44	CIMMYT	Exotic
3.	BCU-4925	29th IBON55	CIMMYT	Exotic
4.	BCU-4927	29th IBON70	CIMMYT	Exotic
5.	BCU-4932	29th IBON100	CIMMYT	Exotic
6.	BCU-4956	10th EMBSN 6	CIMMYT	Exotic
	Testers (six row)			
7.	Lakhan	K12 / IB226	Kanpur, UP	Indigenous
8.	Karan-16	Azam(DWARF)1 / EB7576	DWR, Karnal	Indigenous
9.	K-603	K257 / C138	Kanpur,UP	Indigenous
10.	RD-2035	RD137 / PL101	Durgapura, Rajasthan	Indigenous

3.2 Experimental methods

Selection, hybridization and evaluation of selected genotypes

1st year (*Rabi* season, 2010-11)

- Out of several genotypes grown and maintained by All India Co-ordinated Barley Improvement Project in a crossing block at the Institute Farm at three dates of sowing, among them ten diverse genotypes (4 testers and 6 lines) were selected based on phenotypic and molecular diversity for making the crosses.

- Four testers (six-rowed) were crossed with six lines (two-rowed) to produced 24 F_1s' (excluding reciprocals) in line x tester fashion, using testers as female.
- Standard agronomic practices were followed to raise a good crop.

2nd year (*Rabi* Season, 2011-12)

- The half of experimental materials (24 F_1s' along with parents including standard check i. e. K-603) were grown under rainfed condition in a single row plot of 5 m length in the Compact Family Randomized Block Design with three replications.
- *Per se* performance of parents and crosses were assessed for various traits.
- Remaining half F_1s' were selfed to produce F_2 seeds. Fresh F_1s' and back crosses (B_1 and B_2) were also made.

3rd year (*Rabi* Season, 2012-13)

- For generation mean analysis study, the diverse parents for each trait were selected on the basis of mean performance of parents in Line x Tester analysis under moisture stress (rainfed) condition during *Rabi* 2011-2012. Six generations P_1, P_2, F_1, F_2, B_1 and B_2 from each of the 10 crosses were grown in Compact Family Randomized Block Design with three replications, under two environments i.e. moisture stress (rainfed) and moisture non- stress (irrigated) conditions.
- P_1, P_2 and F_1's were planted in two rows while, B_1s and B_2s were planted in three rows and F_2s in five row plots in each replication. The 3 meter rows were space planted 30 cm apart and a distance of 10 cm was maintained between the plants.
- Moisture non- stress plots were irrigated twice at tillering and flowering initiation stage to have full genetic yield potential.
- The transgressive segregants were sorted out in the same 10 crosses selected for generation mean analysis in F_2 generation.

3.3 Observations recorded

Ten competitive plants from each of the parents and F_1s', 20 plants from backcrosses (B_1 and B_2) and 50 plants from each F_2 population from each replication were randomly selected and tagged for recording of data on following quantitative traits.

3.3.1 Days to 50 % flowering

The number of days taken from sowing to heading in main spike of 50 % plants of a plot was recorded.

3.3.2 Days to maturity

The number of days recorded from sowing to physiological maturity of main spike in hundred per cent plants.

3.3.3 Plant height (cm)

At the physiological maturity the height of individual plant was measured in centimeters from the ground level to the tip of terminal spikelet (excluding the awn) of the main shoot.

3.3.4 Number of effective tillers

At the physiological maturity, the total number of spike bearing tillers in each plant was recorded.

3.3.5 Spike length (cm)

Length of main spike (cm) was measured from the base to the tip of the terminal spikelet, excluding the awn.

3.3.6 Awn length (cm)

Length of the awn was measured in centimeter.

3.3.7 Number of grains per spike

The number of grains per spike was counted from main spike after the harvesting of plant.

3.3.8 Thousand grain weight (g)

One thousand threshed grains were taken randomly after sun drying at 12% moisture level and weighted in gram with the help of electric balance.

3.3.9 Harvest index

Harvest index was calculated as,

$$\text{Economic yield} = \frac{\text{Harvest index}}{\text{Biological yield}} \times 100$$

3.3.10 Grain yield per plant (g)

The weight of filled grains of each plant in grams was recorded.

3.3.11 Stay green

Ability of plant to remain green till maturity was recorded visually following Kumari et *al.* (2007) 0–9 scale and based on the difference between leaf and spike scores (0-9) the genotypes were grouped as non-stay-green (0-1), moderately non-stay-green (>1− <2), moderately stay-green (>2− <3) and stay-green (>3).

3.3.12 Leaf rolling

The leaf rolling was recorded by visual observations in field condition in the scale 1 to 5 to correlate drought tolerance following Chang *et al.* (1982) scale.

3.3.13 Chlorophyll content

Chlorophyll content of leaf was measured directly in the field with the help of SPAD Chlorophyll meter just before heading at morning time.

3.3.14 Stomatal conductance (m mol/m^2/s)

Stomatal conductance was measured by Porometer just before heading.

3.3.15 Proline content

The free Proline content (mg/g) fresh weight of leaves was estimated at anthesis stage according to method given by Bates *et al.* (1973) and as described below.

Principle

The protocol is based on the formation of red colored formazone by proline with ninhydrin in acidic medium, which is soluble in organic solvents like toluene.

Instruments and glassware used

Test tubes, test tube stand, micro-pipettes (20-200 µl, 100-1000 µl and 5 ml), Whatman No. 1 filter papers, visible range spectrophotometer.

Reagents

a) **Glacial acetic acid** (Analytical grade)

b) **Sulphosalycylic acid (3%)**: Three gram of sulphosalycylic acid was dissolved in 100 ml of distilled water.

c) **Orthophosphoric acid (6 N)**: Required volume of orthophosphoric acid (38.1 ml) was taken and volume was made to 100 ml, using distilled water to get 6 N orthophosphoric acid.

d) **Acid ninhydrin**: Ninhydrin (1.25 g) was dissolved in a blend of 30 ml of glacial acetic acid and 20 ml of 6 N orthophosphoric acid.

Procedure for estimation

The 0.5 g leaf sample was homogenized in 5 ml of 3% sulphosalycylic acid using pre washed mortar and pestle. Filtered the homogenate through Whatman No. 1 filter paper and collect filtrate was used for the estimation of proline content. 2 ml of extract was taken in test tube and added 2 ml of glacial acetic acid and 2 ml of ninhydrin reagent. Reaction mixture was heated in a boiling water bath at 100^{o}C for 1hour. Brick red colour was developed. After cooling the reaction mixtures, 4 ml of toluene was added and then transferred to a separating funnel. After thorough mixing, the chromospheres containing toluene is separated and its absorbance was read at 520 nm in spectrophotometer against toluene blank. Standard curve of proline was prepared by taking 100 µg ml-1 concentrations. Free proline content in sample was estimated by referring to a standard curve made from known concentrations of proline by following formula.

The proline concentration was determined from a standard curve and calculated on a fresh weight basis as follows:

$$\text{µmoles proline/gram of fresh weight tissue} = \frac{[(\text{µg proline/ml} \times \text{ml toluene}) / 115.5\ \text{µg/µmole}]}{[(\text{g sample})/5]}$$

3.4 Selection for drought tolerance segregants

Yield under drought (Y_d), yield potential (Y_p), drought susceptibility index (S) and geometric mean (GM) was considered as the potential indicators for drought tolerance of a variety or cross. The selection method was followed according to Schneider *et al*. (1997) which was first on GM followed by selection based on yield under drought (Y_d).

$$GM = \sqrt{Y_p \times Y_d}$$

Where,

GM = Geometric mean of a cross/variety

Y_d = Mean yield of a cross/variety under moisture stress (rainfed)

Y_p = Mean yield of a cross/variety under moisture non-stress (irrigated)

Drought susceptibility Index (S)

$S = [1-(Y_d / Y_p)]/ DII$ (Fischer and Maurer, 1978).

Drought intensity index (DII)

$(DII) = [1-(X_d / X_p)]$

Where,

X_d = Mean yield averaged across crosses/varieties in the moisture stress (rainfed) condition

X_p = Mean yield averaged across crosses/varieties in moisture non-stress (irrigated) condition

3.5 Statistical analysis

3.5.1 Molecular diversity

A total of 14 simple sequence repeat (SSR) markers, selected from Barley SSR linkage map (Liu *et al*., 1996; Ramsay *et al*., 2000; Thiel *et al*., 2003) were used for genetic diversity analysis among 10 barley genotypes. The details of SSR primers used are listed in table below

Table 3.2: List of SSR primers used for detecting parental polymorphism.

S.No.	Primer		Sequence 5'-------------- 3'
1.	Bmac0134	Forward	CCAACTGAGTCGATCTCG
		Reverse	CTTCGTTGCTTCTCTACCTT
2.	Bmag0013	Forward	AAGGGGAATCAAAATGGGAG
		Reverse	TCGAATAGGTCTCCGAAGAAA
3.	EBmac635	Forward	TGCTGCGATGATGAGAACT
		Reverse	TAGGGTAGATCCGTCCCTATG
4.	Bmag613	Forward	AAGAACACCATATGATCCAAC
		Reverse	CTCCATGACTATGAGGAGAAG
5.	Bmag0125	Forward	AATTAGCGAGAACAAAATCAC
		Reverse	AGATAACGATGCACCACC
6.	HvABAIP	Forward	ATGGGAGGGGACAACACCAG
		Reverse	GCCCTCGAACGACCAAACAC
7.	HVM36	Forward	TCCAGCCGAACAATTTCTTG
		Reverse	AGTACTCCGACACCACGTCC
8.	Bmag0378	Forward	CTTTTGTTTCCGTAGCATCTA
		Reverse	ATCCAACTATAGTAGCAAAGCC
9.	Bmag0223	Forward	TTAGTCACCCTCAACGGT
		Reverse	CCCCTAACTGCTGTGATG
10.	Bmac0113	Forward	TCAAAAGCCGGTCTAATGCT
		Reverse	GTGCAAAGAAAATGCACAGATAG
11.	Bmag0353	Forward	ACTAGTACCCACTATGCACGA
		Reverse	ACGTTCATTAAAATCACAACTG
12.	EBmac0806	Forward	ACTAAGTCCTTTCACGAGGA
		Reverse	GTGTGTAGTAGGTGGGTACTTG
13.	GMS27	Forward	CTTTTTCTTTGACGATGCACC
		Reverse	TGAGTTTGTGAGAACTGGATGG
14.	EBmac0824	Forward	GCAAGCTTCCTAAATCCTTA
		Reverse	TGCAGACAGTTTTTCATATACA

3.5.1.1 Isolation of Plant genomic DNA

Young leaves were collected from 20-25 days old barley seedlings and immediately stored in -20^{0}C till further processing. The DNA was extracted following CTAB extraction method (Doyle and Doyle, 1987) with few modifications as described below:

- About 20 mg of leaf sample was placed in 1.2 ml collection micro tube.
- Two tungsten carbide beads (3 mm) were dispensed with the help of TissueLyser bead dispenser in each micro tube and closed with micro tube caps.
- All micro tubes were placed in the TissueLyser adapter set 2 × 96 and pre-cooled at -80ºC for two hours.
- Pre-cooled adapter sets were placed onto TissueLyser arms tightly.
- Leaf samples were disrupted and homogenized by operating TissueLyser for 30 sec at 30 Hz.
- After homogenization, 1 ml pre-warmed CTAB buffer (1M Tris base, 0.5M EDTA, 5M NaCl, CTAB 10%, β-mercaptoethanol, distilled water) was added to each sample and mixed vigorously. The homogenate was transferred into fresh 2 ml micro centrifuge tube and incubated at 65°C in water bath for 1 hour with gentle shaking after each 10 minutes.
- After incubation, samples were taken out and kept at room temperature for few minutes to cool down. Equal volume of phenol: chloroform: isoamylalcohol solution (P: C: I, 25:24:1) was added in each micro centrifuge tubes.
- Samples were mixed gently by inverting the micro centrifuge tubes for a period of 10 minutes at shaker (Bangalore Genei, Bangaluru).
- After shaking, samples were centrifuged at 14000 rpm at room temperature.

- Supernatant was taken out and transferred to new micro centrifuge tube (2 ml) without disturbing the middle layer.
- Five µl of RNAse A solution was added in each sample and incubated at 37^0C for 45 minutes.
- Equal volume of chloroform: isoamylalcohol (C:I, 24:1) was added and mixed gently for 10 minutes at shaker and centrifuged at 14000 rpm at room temperature.
- Supernatant was taken out and transferred to new micro centrifuge tube (1.5 ml) and 2/3 volume of isopropanol (chilled) was added. Tube was mixed gently by inverting the tubes.
- Samples were placed in -20ºc for 30 min. and centrifuged at 14000 rpm for 10 min. at 4ºC.
- Solution was discarded and 200 µl ethanol (70%) was added and centrifuged at 14000 rpm for 10 minutes for washing the DNA pellets.
- The solution was discarded and tubes were inverted for overnight on blotting paper for drying the DNA pellets. DNA pellets were dissolved in 50 µl distilled water and stored at - 20ºC.

Table 3.3: Extraction buffer used for genomic DNA isolation.

Chemical	Stock concentration	Final concentration	Final Volume (100ml)
Tris (pH 7.5)	1 M	100 mM	10
Na CI	5 M	1.4 M	28
EDTA (pH 8.0)	0.5 M	20 mM	4
CTAB	10 %	2%	20
β-Mercaptoethanol	0.02M	0.08mM	0.4
Distilled H_2O	-	-	37.6

3.5.1.2 DNA quality estimation

Analysis of UV absorption by the nucleotides provides a simple and accurate estimation of the concentration of nucleic acids in a sample. Purines and pyrimidines in nucleic acid show absorption maxima around 260 nm (eg. dATP: 259nm; dCTP: 272nm; dTTP: 247nm) if the DNA sample is pure without significant contamination from proteins or organic solvents. The ratio of OD at 260 and 280 nm should be determined to assess the purity of the sample. The DNA quality estimation was done using Bio photometer plus (Eppendorf, USA) with following procedure:

1. Placed Helma (for estimation in small quantity of sample) in the cuvette block.
2. 2 μl distilled water was placed at the lens of the Helma as blank sample using dsDNA analysis mode.
3. All the samples were placed on Helma in 2 μl quantity for DNA quantity/quality estimation and DNA quantity (ng) and quality (OD_{260}/OD_{280} ratio) were recorded.

The ratio (OD_{260}/OD_{280} ratio) thus obtained was used to estimate the nucleic acid purity in the different DNA samples. A ratio of 1.8-2.0 denotes that the absorption in the UV range is due to nucleic acids. A ratio lowers than 1.8 indicates the presence of proteins and/or other UV absorbers. A ratio higher than 2.0 indicates that the samples may be contaminated with chloroform or phenol. In either case (<1.8 or >2.0) samples were re-precipitated to purify the DNA.

3.5.1.3 Polymerase Chain Reaction (PCR)

Polymerase chain reaction was performed to selectively amplify in vitro a specific segment of the total genomic DNA to a billion fold. The most essential requirement of PCR is the availability of a pair of short (typically 20-25 nucleotides) primers having sequence complementary to either end of the target DNA segment (called template DNA) to be synthesized in large amount.

Table 3.4: Standardized concentration of the PCR components used in the present study.

PCR Component	Stock concentration	Final concentration	Vol. used for 15 µl reaction
Primer(F + R)	10 pM	0.7 pM	1.0
Taq DNA Polymerase	5U/ µl	1U	0.2
$Mgcl_2$	25 mM	0.3 mM	0.2
Taq Assay Buffer	10x	1x	1.5
dNTPs	10 mM	0.14 mM	0.2
Genomic DNA	50 -100 ng/ µl	50 ng/15 µl reaction vol.	1.0
HPLC water	-	-	9.9

The components of the PCR reaction were first added in a sterilised 1.5ml micro centrifuge tube thoroughly in a sequence as mentioned in table 3.4 and then mixed thoroughly by vortexing. To each PCR tubes (0.2 ml), 14 µl of reaction mixture was distributed, and finally template DNA of individual barley genotypes was added. The tubes containing reaction mixture were placed in the wells of the thermal cycler block and amplification reaction was carried out with the thermalcycler programme summarised in table 3.5.

For PCR programming all the steps were kept as such except the annealing temperature. For adjustment of concentration of various chemicals, amount of $MgCl_2$ was changed keeping other PCR components as constant. Annealing temperature was determined based on the GC content of the primer using the formula given below:

$$Tm = [2 \times (A+T) + 4 \times (G+C)] - 4$$

This formula gave preliminary information but not the exact annealing temperature. Therefore, the correct annealing temperature was determined based on best PCR amplification. All the amplifications were performed in the Eppendorf Thermo-cycler (USA). After the completion of the PCR, the products were stored at -20ºC until the gel electrophoresis was done.

Table 3.5: The thermocycler programme for PCR used in the study.

Cycle	Temperature	Duration	Objective
First cycle	94°C	4 minutes	Initial denaturation
The next 39 cycles	94°C	45 second	Denaturation
All 40 cycles	T_m °C*	30 second	Annealing
All 40 cycles	72°C	30 second	Extension
At the end of the 40th cycle	72°C	7 minutes	Final extension
Hold	15°C	∞	Hold

*T_m depends on the annealing temperature of the primer used.

3.5.1.4 Visualization of amplification products

The amplified DNA fragments generated through SSR primers were resolved through electrophoresis in 2.5 % agarose gel prepared in TAE [242g Tris-base; 57.1ml glacial acetic acid and 100 ml 0.5 M EDTA (pH 8.0) bring final volume to 1000 ml] buffer. Ethidium bromide solution at a final concentration of 0.03ng/µl was added to the agarose solution.

For electrophoresis, 15 µl of the PCR product was mixed with 2 µl of 6X loading dye (0.25% bromophenol blue in 30% glycerol) and loaded in the slot of the agarose gel. In order to determine the molecular size of the amplified products, each gel was also loaded with 1 µg DNA of a 100 bp DNA size marker (Fermentas, USA). Gel electrophoresis was performed at a constant voltage of 65 V for about 3.5 hours. Finally, the gels were visualized under a UV light source in a gel documentation system (Gel Doc^{TM} XR+, BIO-RAD, USA) and the images of amplification products were captured and stored in a computer for further analysis and future use.

3.5.1.5 Molecular analyses

SSR markers, generated clear and unambiguous bands of various molecular weight sizes, were scored for the presence (1) and absence (0) of the corresponding band among the 10 genotypes. The marker data was used to generate a data matrix in Microsoft Excel 2007. This data matrix was subjected to further analysis using

NTSYS-pc version 2.11. The SIMQUAL program was used to calculate the Jaccard's similarity coefficients. The resulting similarity matrix was used to construct UPGMA (Unweighted Pair Group Method with Arithmetic Mean) based dendrogram. Polymorphic information content (PIC) for each SSR marker was calculated as per the formula:

$$PIC = 1 - \sum_{i=1}^{k} P_i^2$$

Where, Pi is the frequency of the i^{th} allele and k is the total number of different alleles at the specific locus. The binary data was subjected to principal component analysis (PCA) using the EIGEN and PROJ modules of NTSYSpc.

3.5.2 Analysis of variance for line x tester mating design and estimation of combining ability effects

The general and specific combining ability variances and effects analysis will be estimated using line x tester mating design suggested by Kempthorne (1957).

Table 3.6: ANOVA for line x tester analysis

Source	d.f.	S.S.	M.S.S.	F. ratio
Replication	r- 1	rSS	Mr	Mr/Me
Treatment	n- 1	nSS	Mn	Mn/Me
Parents	p- 1	pSS	Mp	Mp/Me
Parents vs Crosses	1	pcSS	Mpc	Mpc/Me
Crosses	lt- 1	cSS	Mc	Mc/Me
Lines (Male)	l- 1	lSS	M1	σ2e + rσ2lt + rtσ2l
Testers (Female)	t- 1	tSS	M2	σ2e + rσ2lt + rlσ2t
Lines x Testers	(l-1) (t-1)	ltSS	M3	σ2e + rσ2lt
Error	(r-1) (n-1)	eSS	Me	σ2e

Where, r = number of replications, n = number of treatments, p = number of parents (l + t), l = number of female lines, t = number of male lines, c = number of crosses (l × t), MSS = mean sum of squares, DF = degree of freedom

The test of significance was carried out with various MSS against eMSS using 'F test' at the respective degrees of freedom for all the sources of variations except lines and testers where MSS due to lines x tester was used. With the help of expectation, covariance of full sibs and half sibs were estimated by using the formula given below:

$$\text{Covariance of half sibs} = \frac{(M_1 - M_2) + (M_2 - M_3)}{r(l + t)}$$

$$\text{Covariance of full sibs} = \frac{(M_1 - M_4) + (M_2 - M_4) + (M_3 - M_4)}{3r} + \frac{6r\ \text{Cov (H.S.)} - r(l + t)\ \text{Cov (H.S.)}}{3r}$$

3.5.2.1 Estimation of general and specific combining abilities effects

The additive model was used to estimate the general and specific combining ability effects of ijkth observation is given here:

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

μ = population mean

g_i = GCA effect of ith female parent

g_j = gca effect of jth male parent

s_{ij} = sca effect of ijth combination

e_{ijk} = error associated with the observation X_{ijk}

i = number of female parents

j = number of male parents

k = number of replication

The gca effects for both male and female parents and sca effects for each cross combination were calculated with the help of following formula:

$$\mu = \frac{X}{ltr}$$

Where,

X… = Total of all hybrid combination over replication

(i) **Lines:** gca effect of i^{th} lines (g_i) = $\frac{Xi..}{tr} - \frac{Xi..}{ltr}$

(ii) **Testers:** gca effect of j^{th} testers (g_i) = $\frac{X.j.}{lr} - \frac{X...}{ltr}$

(iii) **Crosses:** sca effect of ij^{th} lines (s_{ij}) = $\frac{X..j}{r} - \frac{Xi..}{tr} - \frac{X.j.}{lr} - \frac{X...}{ltr}$

Where,

$X_i..$ = Total of i^{th} line over *t* testers and *r* replications

$X._j.$ = Total of j^{th} tester over *l* lines and *r* replications

X_{ij} = ij^{th} combination over all replication

3.5.2.2 Standard errors for combining ability effects

In order to test the significance of gca/sca effects or that of the difference of any two gca/sca effects, the SE and SEd were calculated as under:

(a) SE for gca effects of lines: SE $g_i = (Me/r \times t)^{1/2}$

(b) SE for gca effects of testers: SE $g_j = (Me/r \times l)^{1/2}$

(c) SE for sca effects of testers: $SE_{sij} = (Me/r)^{1/2}$

(d) SE for difference between two sca effects: SE (Sij-Skl) = $(2Me/r)^{1/2}$

The critical difference (CD) values in each case were computed by multiplying their corresponding SE value with the table 't' values at error degrees of freedom at P= 0.05 and 0.01.

3.5.2.3 Proportional contribution of lines, testers and their interactions to total variance

$$\text{Contribution of Lines} = \frac{\text{SS (l)}}{\text{SS (Crosses)}} \times 100$$

$$\text{Contribution of Testers} = \frac{\text{SS (t)}}{\text{SS (Crosses)}} \times 100$$

$$\text{Contribution of Lines} \times \text{Testers} = \frac{\text{SS } (l \times t)}{\text{SS (Crosses)}} \times 100$$

3.5.3 Estimation of heterosis

Heterosis in F_1s' will be calculated as the difference of F_1 hybrid performance from the better parents (Heterobeltiosis) and standard checks (Standard heterosis) by using the formulae (Kempthorne, 1957).

$$\text{Heterobeltiosis (\%)} = \frac{(\overline{F}_1 - \overline{BP})}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{(\overline{F}_1 - \overline{C})}{\overline{C}} \times 100$$

Where,

$\overline{F}_1$ = mean performance of F_1.

$\overline{F_2}$ = mean performance of F_2.

$\overline{BP}$ = mean performance better parent.

$\overline{C}$ = mean performance of check variety.

Test of significance of heterosis

To test the significance of heterosis, the formula proposed by Arunachalam (1976) was used.

SE (Diff.) for ($\overline{F_1}$ - $\overline{BP}$ or $\overline{C}$) = $(2MSe/3r)^{1/2}$

CD = SE (Diff.) × t value at 5 and 1 per cent significance at respective error degree of freedom.

Where,

MSe = Mean sum of squares due to error.

3.5.4 Heritability (Narrow Sense)

Heritability (h^2) estimate was worked out by using the formula suggested by Lush (1949) and Burton and De Vance (1953):

$$h^2 \text{ (Narrow sense)} = \frac{\sigma^2_A}{\sigma^2_P} \times 100$$

Where,

h^2 (ns) = heritability expressed in per cent

σ^2A = Additive genetic variance

σ^2P = Phenotypic variance

The estimates of heritability are categorized as High (>30%), Moderate (>10% and <30%) and Low (<10%). In general, all the traits exhibited moderate to high heritability.

3.5.5 Expected genetic advance

It was calculated as per formula suggested by Lush (1949).

(a) Genetic advance (GA) = (K) (h^2) (σP)

(b) Genetic advance as % of mean = GA $\sqrt{X}$ ×100

Where,

h^2 = estimates of heritability (absolute value)

σ_P = phenotypic standard deviation

K = selection differential at 5% selection intensity, i.e., 2.06

X = population mean for the concerned character

3.5.6 Estimation of generation mean analysis

Generation mean analysis approach will be calculated as per Mather (1949) and Mather & Jinks (1977).

3.5.6.1 Simple scaling test

Adequacy of scale must satisfy two conditions namely, additivity of gene effects and independence of heritable components from non-heritable ones. The test of first condition provides information regarding absence or presence of gene interactions. The test of adequacy of scales is important because in most of the cases the estimation of additive and dominance components of variances are made assuming the absence of gene interaction. Mather (1949) and Hayman and Mather (1955) gave following four tests for scale effects:

$$A = 2.\overline{B}_1 - \overline{P}_1 - \overline{F}_1 B = 2.\overline{B}_2 - \overline{P}_2 - \overline{F}_1 C = 4.\overline{F}_2 - 2.\overline{F}_1 - \overline{P}_1 - \overline{P}_2\ D$$
$$= 2.\overline{F}_2 - \overline{B}_1 - \overline{B}_2$$

When the scale is adequate, the values of A, B, C and D should be zero within the limit of their respective Standard Errors.

Variances of above scales

$$V_A = 4.V_{\overline{B}_1} + V_{\overline{P}_1} + V_{\overline{F}_1} V_B = 4.V_{\overline{B}_2} + V_{\overline{P}_2} + V_{\overline{F}_1} V_C$$
$$= 16.V_{\overline{F}_2} + 4.V_{\overline{F}_1} + V_{\overline{P}_1} + V_{\overline{P}_2}\ V_D = 4.V_{\overline{F}_2} + V_{\overline{B}_1} + V_{\overline{B}_2}$$

Standard errors of above scale:

$$SE_A = V_A SE_B = V_B SE_C = V_C SE_D = V_D$$

Now, the‘t’ values are calculated as follows:

$$t_A = \frac{A}{SE_A} t_B = \frac{B}{SE_B} t_C = \frac{C}{SE_C} t_D = \frac{D}{SE_D}$$

The calculated value of ‘t’ are to be compared with tabulated value of ‘t’ at 5% level of significance. In each test, the degree of freedom is sum of the degrees of freedom of various generations (total number of observations - total number of replications) involved.

3.5.6.2 Joint scaling test

The main drawback of simple scale tests is that out of six populations only three or four are included in the test at a time. In order to overcome this problem, Cavalli (1952) gave the method ‘Joint scaling test’ which includes any combination of families at a time. The ‘weighted least square method’ developed by Hayman (1960) was used to estimate the parameters m, d and h. Here, the weights are defined as the reciprocal of standard error. From these estimates, the expected generation means were calculated and compared with the observed generation mean values using a χ^2 test. A significant χ^2 value indicates that the model is not adequate and the non-allelic interactions are added in the model.

3.5.6.3 Components of generation means

Hayman (1958) and Jinks and Jones (1958) devised the six parameter model for the estimation of various genetic components; these components were estimated according to Hayman (1958) as follows:

$$\mathrm{m} = \mathrm{mean} = \overline{\mathrm{F}}_2 \quad \mathrm{d} = \mathrm{Additive\ effects} = \overline{\mathrm{B}}_1 - \overline{\mathrm{B}}_2 \mathrm{h} = \mathrm{Dominance\ effects}$$

$$= \overline{\mathrm{F}}_1 - 4.\overline{\mathrm{F}}_2 - \tfrac{1}{2}.\overline{\mathrm{P}}_1 - \tfrac{1}{2}.\overline{\mathrm{P}}_2 + 2.\overline{\mathrm{B}}_1 + 2.\overline{\mathrm{B}}_2 \mathrm{i}$$

$$= \mathrm{Additive} \times \mathrm{Additive\ type\ of\ gene\ interaction}$$

$$= 2.\overline{\mathrm{B}}_1 + 2.\overline{\mathrm{B}}_2 - 4.\overline{\mathrm{F}}_2 \mathrm{j}$$

$$= \mathrm{Additive} \times \mathrm{Dominance\ type\ of\ gene\ interaction}$$

$$= \overline{\mathrm{B}}_1 - \tfrac{1}{2}.\overline{\mathrm{P}}_1 - \overline{\mathrm{B}}_2 + \tfrac{1}{2}.\overline{\mathrm{P}}_2 \mathrm{l}$$

$$= \mathrm{Dominance} \times \mathrm{Dominance\ type\ of\ gene\ interaction}$$

$$= \overline{\mathrm{P}}_1 + \overline{\mathrm{P}}_2 + 2.\overline{\mathrm{F}}_1 + 4.\overline{\mathrm{F}}_2 - 4.\overline{\mathrm{B}}_1 - 4.\overline{\mathrm{B}}_2$$

Variances of above parameters:

$$\mathrm{V_m} = \mathrm{V}_{\overline{\mathrm{F}}_2} \quad \mathrm{V_d} = \mathrm{V}_{\overline{\mathrm{B}}_1} + \mathrm{V}_{\overline{\mathrm{B}}_2} \quad \mathrm{V_h} = \mathrm{V}_{\overline{\mathrm{F}}_1} + 16.\mathrm{V}_{\overline{\mathrm{F}}_2} + \tfrac{1}{4}.\mathrm{V}_{\overline{\mathrm{P}}_1} + \tfrac{1}{4}.\mathrm{V}_{\overline{\mathrm{P}}_2} + 4.\mathrm{V}_{\overline{\mathrm{B}}_1} \mathrm{V_i}$$

$$= 4.\mathrm{V}_{\overline{\mathrm{B}}_1} + 4.\mathrm{V}_{\overline{\mathrm{B}}_2} + 16.\mathrm{V}_{\overline{\mathrm{F}}_2} \mathrm{V_j} = \mathrm{V}_{\overline{\mathrm{B}}_1} + \tfrac{1}{4}.\mathrm{V}_{\overline{\mathrm{P}}_1} + \mathrm{V}_{\overline{\mathrm{B}}_2} + \tfrac{1}{4}.\mathrm{V}_{\overline{\mathrm{P}}_2} \mathrm{V_l}$$

$$= \mathrm{V}_{\overline{\mathrm{P}}_1} + \mathrm{V}_{\overline{\mathrm{P}}_2} + 4.\mathrm{V}_{\overline{\mathrm{F}}_1} + 16.\mathrm{V}_{\overline{\mathrm{F}}_2} + 16.\mathrm{V}_{\overline{\mathrm{B}}_1} + 16.\mathrm{V}_{\overline{\mathrm{B}}_1}$$

Standard errors of the parameters:

$$SE_m = \sqrt{V_m} SE_d = \sqrt{V_d} SE_h = \sqrt{V_h} SE_i = \sqrt{V_i} SE_j = \sqrt{V_j} SE_l = \sqrt{V_l}$$

Now, the‘t’ values are calculated as followed:

$$t_m = \frac{m}{SE_m}$$

$$t_d = \frac{d}{SE_d} t_h = \frac{h}{SE_h} t_i = \frac{i}{SE_i}$$

$$t_j = \frac{j}{SE_j}$$

$$t_l = \frac{l}{SE_l}$$

The calculated value of ‘t’ are to be compared with tabulated value of ‘t’ at 5% level of significance. In each test, the degree of freedom is sum of the degrees of freedom of various generations (total number of observations - total number of replications) involved.

Chapter IV

EXPERIMENTAL FINDINGS

The present investigation was carried out during the *Rabi* season of 2010-11, 2011-12 and 2012-13 at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Data recorded on various yield, it's contributing traits and drought tolerance related traits were analyzed following standard statistical procedures and statistical software Windostat 8.1. The mean performances of 6 lines, 4 testers and their 24 crosses for all the traits studied were presented in appendix III, IV and V. The results of present investigation involving different experiments are presented as follows:

4.1 Molecular diversity analysis for detecting parental polymorphism

4.2 Analysis of variance for line x tester mating design

4.3 General combining ability effects (GCA)

4.4 Specific combining ability effects (SCA)

4.5 Estimation of components of genetic variance

4.6 Proportional contribution of lines, testers and their interaction to total variance

4.7 Estimation of general means, heritability and expected genetic advance

4.8 Extent of heterosis

4.9 Estimates of the gene actions through generation mean analysis

4.10 Studies on transgressive segregants and drought tolerant recombinants in F_2 generation

4.1 Molecular diversity analysis for detecting parental polymorphism

A total of 14 simple sequence repeat (SSR) markers, selected from barley SSR linkage map were used for genetic diversity analysis among 10 selected barley parents. 14 SSRs produced reproducible and polymorphic banding patterns which are shown in Table 4.1. These SSRs yielded a total of 29 polymorphic bands. The number of polymorphic bands per primer ranged from 2 to 3 with an average of 2.21 (Table 4.1). The polymorphic information content (PIC) of the 14 SSR primers ranged from 0.52 to 0.80 with an average PIC of 0.73. Gel images showing typical SSR banding pattern generated by the primers Bmac0113, Bmag0353 and EBmac0824 have been presented in Fig 4.1, Fig 4.2 and Fig 4.3, respectively.

The relationship between the 10 barley genotypes was studied by the un-weighted pair group method arithmetic average (UPGMA) based cluster analysis of data developed by 14 SSR markers. The Jaccard's similarity (Table 4.2) was used to produce a dendrogram to obtain the clustering of 10 barley genotypes (Fig 4.4). The pair wise similarity was calculated by Jaccard's similarity coefficients, which ranged from 0.05 to 0.76 with an average similarity of 0.35. The highest similarity coefficient (0.76) was observed between the genotypes Karan16 and RD2035, whereas lowest similarity coefficient (0.05) was observed between the genotypes Lakhan and BCU4910. To reveal genetic distance among the 10 parents, a dendrogram was constructed. The 10 genotypes were clustered into three groups namely, Cluster I, II and III indicating a wide genetic diversity. Cluster I consisted of only one genotype i.e. Lakhan whereas cluster II composed of four genotypes *viz.*, Karan 16, RD 2035, BCU 4932 and BCU 4956. The major cluster, cluster III made up of five genotypes *viz.*, K 603, BCU 4910, BCU 4922, BCU 4925 and BCU 4927.

4.2 Analysis of variance for line x tester mating design

The experimental materials (24 F_1s' along with 6 lines and 4 testers including standard check i.e. K 603) were tested in different environments. During 2011-2012 experimental materials were grown under rainfed condition only while during 2012-

13 under both rainfed as well as irrigated conditions. The data for all the quantitative traits were subjected to analysis of variance (ANOVA). Treatment variations showed highly significant differences for all the characters studied (Table 4.3.1, 4.3.2, 4.3.3). The differences among the parents were highly significant for most of the traits over the environment. The variance due to parents was further partitioned into variance due to lines (male) and testers (female). During rainfed condition (2011-12) the mean squares due to parents vs. crosses component showed significant differences for all the characters studied except spike length, number of grains per spike, harvest index and grain yield per plant. The mean squares due to lines and testers were highly significant for most of the characters studied except, days to 50% flowering, days to maturity, grain yield per plant and proline content for lines while, days to 50% flowering, days to maturity, awn length and proline content for testers. The line × tester interaction was significant for almost all the traits under study except days to 50% flowering and days to maturity. During rainfed condition (2012-13) the mean squares due to parents vs. crosses component showed significant differences for all the characters studied except chlorophyll content. The mean squares due to lines and testers were highly significant for most of the characters studied except, plant height, number of effective tillers, spike length, number of grains per spike, harvest index and grain yield per plant for lines while, days to 50% flowering, spike length, awn length, number of grains per spike, harvest index, chlorophyll content and proline content in case of testers. The line × tester interaction was significant for plant height, number of grains per spike, thousand grain weight, harvest index and stomatal conductance. Further, the mean squares due to parents vs. crosses component showed significant differences for all the characters except proline content under irrigated condition (2012-13). Number of grains per spike and thousand grain weight showed significant differences for mean squares due to lines while most of the traits revealed significant differences for mean squares due to testers except spike length, number of grains per spike and chlorophyll content. The line × tester interaction was significant for plant height, harvest index and chlorophyll content under irrigated condition (2012-13).

4.3 General combining ability effects (GCA)

The high positive values of GCA effects indicated that their contribution in transferring these characters to their hybrids is high and vice versa. The estimates of general combining ability (gca) effects of ten divers parents (6 lines + 4 testers) for all the traits are presented in Table 4.4.1, 4.4.2 and 4.4.3. The positive and significant gca effects were considered to be desirable for number of effective tillers, spike length, awn length, number of grains per spike, harvest index, thousand grain weight, grain yield per plant, chlorophyll content and proline content. Further, in case of plant height, days to 50% flowering and days to maturity the negative and significant gca effects were considered to be desirable. Stomatal conductance is considered as an important trait for drought resistant. Whenever there is moisture stress (rainfed), lower stomatal conductance is a desirable trait whereas reverse is true under moisture non-stress (irrigated) condition. The estimates of general combining ability (gca) effects of parents in the present study have been particularized trait wise in the following paragraphs.

4.3.1 Days to 50% flowering

General combining ability effects for most of the lines and testers were observed to have negative and significant values. Among lines BCU 4925 (-2.29), BCU 4927 (-2.70) and BCU 4956 (-3.04) showed significant negative gca effects under rainfed condition during 2011-12 and BCU 4932 (-2.41) during 2012-13. Similarly, BCU 4956 (-2.95) revealed negatively significant gca effects under irrigated condition (2012-13). In case of testers, Karan 16 (-0.48) and Lakhan (-0.44) showed negatively significant gca effects under rainfed condition during 2011-12 whereas Karan 16 (-2.89) during 2012-2013. Similarly, RD 2035 (-1.82) showed significant gca effects for days to 50% flowering under irrigated condition (2012 -13). Among these BCU 4956 and Karan 16 were best general combiners over the environments.

4.3.2 Days to maturity

Among lines, BCU 4927 (-3.40), BCU 4956 (-3.40) and BCU 4925 (-1.48) showed significant negative gca effects for days to maturity under rainfed condition (2011-12). BCU 4956 (-2.64) revealed significant negative gca effects under irrigated condition (2012-13). Similarly, among testers Karan 16 (-0.51), K-603 (-0.40) and Lakhan (-0.35) revealed negative significant gca effects under rainfed condition during 2011-12 whereas Karan 16 (-2.79) under rainfed condition during 2012-2013. RD 2035 (-1.61) exhibited negative significant gca effects for days to maturity under the irrigated condition (2012-13). Thus line BCU 4956 was observed best combiner for days to maturity over the environments.

4.3.3 Plant height

General combining ability effects for most of the lines and testers were observed to have significant values. BCU 4956 (-9.10) and BCU 4922 (-2.49) revealed significant negative gca effects under rainfed (2011-12). BCU 4956 (-3.46) and BCU 4932 (-4.31) affirmed negative significant gca effects under the irrigated and rainfed condition (2012-2013), respectively. Further, testers Lakhan (-5.05) and Karan 16 (-2.56) affirmed negative significant gca effects for plant height under rainfed condition 2011-12 and 2012-13, respectively. Similarly, RD 2035 (-6.48) and Karan 16 (-3.46) showed negative significant gca effects under irrigated condition (2012-2013).

4.3.4 Number of effective tillers

Among lines, BCU 4922 (2.56), BCU 4910 (1.93) and BCU 4932 (0.98) proclaimed positive significant gca effects under rainfed condition (2011-12) whereas BCU 4956 (1.63) under irrigated condition (2012-13). In case of testers, Karan 16 (0.90) revealed positive and significant gca effects under rainfed condition (2011-12). Whereas Lakhan (1.57) and K 603 (1.22) had significant positive gca effects under irrigated condition while Lakhan (2.35) under the rainfed condition (2012-2013) for number of effective tillers.

4.3.5 Spike length

Most of the lines and testers revealed significant gca effects for spike length. BCU 4910 (1.01) and BCU 4932 (0.58) expressed significant positive gca effects under rainfed condition during 2011-12 whereas BCU 4932 (0.66) during 2012-2013. BCU 4922 (0.85) revealed significant positive gca effects under the irrigated condition (2012-13). Among testers, K-603 (0.50) affirmed positive significant gca effects under irrigated condition (2012-13) while Karan 16 under rainfed condition during 2011-12 (0.62) as well as 2012-2013 (0.73) which was proved to be best general combiner for spike length over the environments.

4.3.6 Awn length

BCU 4922 (1.31) and BCU 4910 (0.82) expressed significant positive gca effects for awn length under rainfed condition during 2011-12 while, BCU 4932 (1.01) during 2012-13. Similarly, BCU 4927 (0.77) showed positive significant gca effects under irrigated condition (2012-2013). Among testers Lakhan (1.75) and K 603 (0.62) revealed significant positive gca effects under rainfed condition during 2012-13. Karan 16 (1.33) and Lakhan (0.97) had positive significant gca effects under rainfed condition (2011-12) and irrigated condition (2012-13), respectively. Among these, Lakhan was observed as best general combiner over the environments.

4.3.7 Number of grains per spike

BCU 4927 (6.56) and BCU 4925 (4.20) proclaimed positive significant gca effects under rainfed condition during 2011-12 whereas BCU 4910 (2.36) during 2012-13. In case of testers, K 603 (1.29) and Karan 16 (0.73) revealed positive significant gca effects under rainfed (2011-12) and irrigated condition (2012-13) respectively for number of grains per spike.

4.3.8 Thousand grain weight

The highest positive significant estimate was observed for line BCU 4932 (9.14) followed by BCU 4910 (6.66) and BCU 4922 (5.27) under rainfed condition during 2011-12 whereas BCU 4956 under both the rainfed condition (6.16) and irrigated condition (5.22) during 2012-13. Among testers, Karan 16 (5.23) revealed positive and significant gca effects under rainfed condition during 2011-12. On the other hand, Lakhan (3.29) and K 603 (3.13) affirmed positive significant gca effects for this trait under irrigated condition and rainfed condition (2012-13), respectively. Among these, BCU 4956 was observed as best general combiner over the environments.

4.3.9 Harvest index

Most of the lines and testers revealed significant gca effects for harvest index. Among lines, BCU 4922 (12.78) and BCU 4925 (3.73) proclaimed positive significant gca effects under rainfed condition during 2011-12 whereas BCU 4956 (1.81) under rainfed condition (2012-13). Similarly, BCU 4910 (1.78) had positive significant gca effects under irrigated condition (2012-13). In case of testers, K 603 revealed positive significant gca effects under rainfed condition during 2011-12 (2.70) as well as 2012-13 (3.01).

4.3.10 Grain yield per plant

General combining ability effects for most of the lines and testers were observed significant for grain yield per plant. The highest positive significant estimate was observed for line BCU 4922 (5.58) followed by BCU 4910 (4.25) and BCU 4932 (1.95) whereas among testers, Karan 16 (1.58) revealed positive significant gca effects under rainfed condition (2011-12). On the other hand lines BCU 4927 (1.91), BCU 4932 (1.81) and tester Lakhan (1.98) gave positive significant gca effects under irrigated condition (2012-13). Similarly, BCU 4927 (2.44), K 603 (2.99) and Lakhan (2.09) affirmed positive significant gca effects for this trait under rainfed condition (2012-13). Among these lines BCU 4927 and BCU 4932 and tester Lakhan was observed as top general combiners over the environments.

4.3.11 Chlorophyll content

BCU 4922 (2.43) and BCU 4956 (4.97) expressed significant positive gca effects under rainfed condition (2011-12) and irrigated condition (2012-13), respectively while BCU 4925 (1.97) showed positive significant gca effects for chlorophyll content under rainfed condition (2012-13). On the other hand, Lakhan (0.91) affirmed positive significant gca effects for this trait under rainfed condition (2011-12).

4.3.12 Stomatal conductance

Most of the lines and testers revealed significant gca effects for stomatal conductance. Whenever there is moisture stress (rainfed), lower stomatal conductance is a desirable trait, whereas reverse is true under moisture non-stress (irrigated) condition. Among lines, BCU 4932 (-60.75) and BCU 4922 (-42.58) proclaimed negative significant gca effects under rainfed condition during 2011-12. In case of testers, Karan 16 (-39.08), Lakhan (-24.97) and K 603 (-22.91) revealed significant negative gca effects under rainfed condition during 2011-12 whereas Lakhan (-44.90) during 2012-13. Similarly, Karan 16 (39.71) affirmed significant positive gca effects under irrigated condition (2012-13) for stomatal conductance.

4.3.13 Proline content

General combining ability effects for most of the lines and testers were significant for proline content. BCU 4922 (0.21) revealed positive significant gca effects under rainfed condition (2011-12). Similarly, BCU 4925 (0.09) and BCU 4932 (0.10) showed positive significant gca effects for proline content under rainfed condition while BCU 4927 (0.35) under irrigated condition (2012-2013). On the other hand, Karan 16 (0.17) and K 603 (0.60) had positive significant gca effects under rainfed condition during 2011-12 and Lakhan (0.27) during 2012-13.

4.4 Specific combining ability effects (SCA)

The estimates of specific combining ability effects (sca) for all the traits are presented in Table 4.5.1, 4.5.2 and 4.5.3 and have been particularized trait wise, in the following paragraphs.

4.4.1 Days to 50% flowering

The differences between the estimates of sca effects for days to 50% flowering varied considerably. 8 crosses were revealed significant sca effects of which 4 crosses were negative and desirable. The crosses, BCU 4927 x Karan 16 (-3.85) and BCU 4925 x K 603 (-3.60) were considered desirable for days to 50% flowering under rainfed condition (2011-12) whereas, BCU 4956 x K 603 affirmed desirable under both the rainfed (-3.33) and irrigated condition (-1.92) 2012-13.

4.4.2 Days to maturity

The estimates of sca effects for days to maturity were significant with overall range from -3.63 (BCU 4925 x K 603) to 4.93 (BCU 4925 x RD 2035). 10 crosses were revealed significant sca effects of which 6 crosses were negative and desirable. The negative significant estimates of sca effects were observed for BCU 4925 × Lakhan (-3.79) and BCU 4925 x K 603 (-3.63) during 2011-12 whereas BCU 4925 x Lakhan (-2.38) and BCU 4956 x K 603 (-2.40) during 2012-13 under rainfed condition. Similarly, BCU 4956 x K 603 (-2.19) and BCU 4927 x Lakhan (-2.14) showed negative significant estimates of sca effects under irrigated condition (2012-13) which were considered desirable crosses for days to maturity. Among these, BCU 4956 x K 603 revealed as best specific combiner over the environments.

4.4.3 Plant height

The differences between the estimates of sca effects for plant height varied considerably. The negatively significant sca effects were considered desirable for plant height. Under rainfed condition (2011-12) BCU 4927 x Lakhan (-9.38) showed highest negative significant sca effects followed by BCU 4922 x RD 2035 (-4.87), BCU 4927 x K 603 (-4.61), BCU 4910 x RD 2035 (-4.46), BCU 4925 x K 603 (-3.18), BCU 4956 x RD 2035 (-3.07) and BCU 4932 x Karan 16 (-3.02). Similarly, BCU 4910 x Lakhan (-9.57), BCU 4922 x RD 2035 (-7.38), BCU 4922 x K 603 (-6.60), BCU 4956 x Lakhan (-4.82) were considered desirable under irrigated condition (2012-13) whereas BCU 4910 x RD 2035 (-3.57), BCU 4922 x K 603 (-5.14), BCU 4932 x Karan 16 (-12.67) and BCU 4956 x K 603 (-4.60) were scored desirable under rainfed condition (2012-13). Among these, BCU 4922 x K 603 and BCU 4932 x Karan 16 were recorded as best specific combiners over the environments.

4.4.4 Number of effective tillers

The estimates of sca effects for this trait were significant for most of the crosses. BCU 4925 x Karan 16 and BCU 4925 x RD 2035 (4.03) followed by BCU 4910 x Lakhan (2.57), BCU 4932 x K 603 (2.52), BCU 4956 x Karan 16 (2.42), BCU 4922 x K 603 (1.61), BCU 4927 x Lakhan (1.40), BCU 4922 x Lakhan (1.38) and BCU 4927 x K 603 (1.37) were observed desirable for number of effective tillers under rainfed condition (2011-12). The crosses, BCU 4922 x Lakhan (4.27), BCU 4925 x K 603 (2.63), BCU 4927 x RD 2035 (4.69) and BCU 4956 x Karan 16 (2.65) had positive significant sca effects under rainfed condition (2012-13) and BCU 4910 x RD 2035 (3.20), BCU 4922 x Lakhan (2.38), BCU 4922 x Karan 16 (3.54), BCU 4932 x Lakhan (3.20) and BCU 4956 x K 603 (2.47) under irrigated condition (2012-13) for number of effective tillers. Among these, BCU 4922 x Lakhan was observed as best specific combiner over the environments.

4.4.5 Spike length

Nineteen crosses revealed significant sca effects for spike length. BCU 4925 x RD 2035 (2.37), BCU 4956 x K 603 (1.46), BCU 4927 x Lakhan (1.34), BCU 4932 x RD 2035 (0.94), BCU 4925 x Karan 16 (0.90), BCU 4922 x Karan 16 (0.82) and BCU 4927 x RD 2035 (0.80) recorded as desirable crosses under rainfed condition (2011-12). Similarly, BCU 4925 x Karan 16 (1.59) revealed positively significant sca effects under rainfed condition and BCU 4932 x K 603 (1.18) under irrigated condition during 2012-13. Among these, BCU 4925 x Karan 16 was observed as best specific combiner over the environments.

4.4.6 Awn length

Fifteen crosses revealed significant sca effects of which 6 crosses were positive and desirable for awn length. The crosses, BCU 4932 x K 603 (2.18), BCU 4925 x Karan 16 (2.06), BCU 4922 x K 603 (1.81) and BCU 4925 x RD 2035 (1.57) appeared as desirable under rainfed condition (2011-12) while BCU 4922 x Lakhan (2.86) during 2012-13. The cross BCU 4932 x K 603 (1.44) had positively significant sca effects under irrigated condition (2012-13). Among these, BCU 4932 x K 603 was observed as best specific combiner over the environments.

4.4.7 Number of grains per spike

Twenty crosses revealed significant sca effects of which 9 crosses were positive and desirable for number of grains per spike. Under rainfed condition of 2011-12, BCU 4927 x RD 2035 (15.61), BCU 4925 x Lakhan (7.76), BCU 4910 x Karan 16 (4.31), BCU 4922 x Lakhan (3.79), BCU 4956 x Karan 16 (2.92) and BCU 4932 x Lakhan (2.65) were disclosed as desirable for number of grains per spike. Similarly, BCU 4910 x Lakhan (3.01) and BCU 4922 x K 603 (2.57) were scored positively significant under rainfed and BCU 4922 x RD 2035 (2.17) under irrigated condition during 2012-13.

4.4.8 Thousand grain weight

The estimates of sca effects were significant for most of crosses for thousand grain weight. The crosses, BCU 4922 x K 603 (11.51), BCU 4925 x RD 2035 (11.42), BCU 4925 x Karan 16 (8.32), BCU 4927 x K 603 (6.97), BCU 4910 x K 603 (5.55), BCU 4956 x RD 2035 (5.51), BCU 4927 x Lakhan (4.15) and BCU 4956 x Lakhan (3.47) were proclaimed as desirable for thousand grain weight under rainfed condition of 2011-12. BCU 4910 x Karan 16 (5.01), BCU 4932 x Lakhan (6.08) and BCU 4956 x RD 2035 (3.02) were scored as desirable under rainfed and BCU 4922 x Lakhan (5.15), BCU 4922 x Karan 16 (4.39) and BCU 4932 x K 603 (6.79) under irrigated condition of 2012-13 for thousand grain weight. Among these, BCU 4956 x RD 2035 was revealed as best specific combiner over the environments.

4.4.9 Harvest index

Twenty two crosses revealed significant sca effects for harvest index. The fascinating crosses scored were BCU 4925 x Karan 16 (10.35), BCU 4956 x K 603 (9.97), BCU 4932 x K 603 (9.76), BCU 4925 x RD 2035 (8.71), BCU 4910 x Lakhan (4.89) and BCU 4927 x Lakhan (4.14) under rainfed condition (2011-12). Further the crosses BCU 4922 x Lakhan (6.41), BCU 4925 x K 603 (5.42), BCU 4927 x K 603 (5.38) and BCU 4956 x Karan 16 (5.34) were observed as desirable under rainfed and BCU 4956 x K 603 (4.14) was desirable for harvest index under irrigated condition of 2012-13. Among these, BCU 4956 x K 603 was recorded as best specific combiner over the environments.

4.4.10 Grain yield per plant

The estimates of sca effects were significant for most of the crosses for grain yield per plant of which BCU 4910 x Lakhan (6.73), BCU 4922 x K 603 (5.88), BCU 4925 x RD 2035 (4.82) and BCU 4927 x RD 2035 (2.71) were observed as desirable under rainfed condition of 2011-12. Similarly, the crosses BCU 4922 x Lakhan (4.79), BCU 4927 x RD 2035 (4.55), BCU 4932 x Lakhan (3.11) and BCU 4956 x Karan 16 (3.26) were recorded as desirable under rainfed the crosses BCU 4910 x RD 2035 (4.80), BCU 4925 x K 603 (3.51), BCU 4932 x Lakhan (3.70) and BCU 4956 x Karan 16 (3.16) were scored as desirable for grain yield per plant under irrigated condition of 2012-13 (Tables 4.5.1, 4.5.2 and 4.5.3). Among these, BCU 4932 x Lakhan and BCU 4956 x Karan 16 were the best specific combiners for grain yield per plant over the environments.

4.4.11 Chlorophyll content

The estimates of sca effects were significant for 18 crosses of which 9 crosses showed positive significant sca effects for chlorophyll content. Under rainfed condition (2011-12) BCU 4932 x RD 2035 (4.94), BCU 4922 x Karan 16 (4.42) and BCU 4925 x Lakhan (4.31) were observed as fascinating crosses for chlorophyll content. Similarly, BCU 4910 x RD 2035 (2.35) and BCU 4932 x K 603 (3.14) were considered as desirable under rainfed condition (2012-13) while BCU 4910 x Lakhan (4.13), BCU 4925 x Karan 16 (3.33), BCU 4925 x RD 2035 (3.14) and BCU 4932 x RD 2035 (5.35) scored as desirable under irrigated condition (2012-13). Among these BCU 4932 x RD 2035 was the best specific combiner for chlorophyll content over the environments.

4.4.12 Stomatal conductance

The estimates of sca effects were significant for 10 crosses for stomatal conductance. Negatively significant sca effects were considered as desirable under rainfed condition and therefore only BCU 4956 x K 603 (-92.16) was considered as desirable under rainfed condition of 2011-12. Similarly, BCU 4910 x Karan 16 (-100.54) and BCU 4925 x Lakhan (-88.76) under rainfed condition of 2012-13 and BCU 4927 x RD 2035 (117.60) and BCU 4927 x Karan 16 (89.79) were scored as desirable for stomatal conductance under irrigated condition of 2012-13 as positively significant sca effects were considered as desirable under irrigated condition.

4.4.13 Proline content

The estimates of sca effects were significant for 5 crosses, of which 2 crosses revealed positive estimates. The lowest estimate of sca effect was -0.33 (BCU 4922 x Karan 16, BCU 4910 x K 603) and the highest was 0.48 (BCU 4927 x RD 2035). The cross, BCU 4956 x K 603 (0.37) was observed as desirable for proline content under rainfed condition (2011-12) while BCU 4927 x RD 2035 (0.48) during 2012-13.

4.5 Estimation of components of genetic variance

The estimation of components of genetic variance i.e., variance due to lines (male σ^2gm), testers (female σ^2gf), gca (σ^2gca), sca (σ^2sca), additive (σ^2A), dominance (σ^2D) and average degree of dominance $\sqrt{(\sigma^2 D / \sigma^2 A)}$ were estimated for all the traits under moisture stress (rainfed) condition during *rabi* 2011-12 (Table 4.6.1), *rabi* 2012-13 (Table 4.6.2) and moisture non-stress (irrigated) during *rabi* 2012-13 (Table 4.6.3).

A wide range of variation was observed in the estimates of genetic components of variance for all the traits under both rainfed (2011-12, 2012-13) and irrigated environments (2012-13). The estimates of variance due to lines (male σ^2gm) were higher than variance due to testers (female σ^2gf) for all the traits over the environments. On the other hand, the estimates of specific combining ability variances (σ^2sca) were higher than general combining ability variances (σ^2gca) for most of the traits over the environments. The magnitude of σ^2A was higher than σ^2D for days to 50% flowering, days to maturity, plant height, thousand grain weight, harvest index, grain yield per plant while σ^2D was higher than σ^2A for number of effective tillers, spike length, awn length, number of grains per spike, chlorophyll content, stomatal conductance and proline content under rainfed condition during 2011-12. Days to maturity, number of effective tillers, spike length, awn length, thousand grain weight, grain yield per plant and proline content revealed the magnitude of σ^2A was higher than σ^2D under rainfed condition (2012-13) while days to maturity, plant height, thousand grain weight, chlorophyll content, and proline content under irrigated condition (2012-13). The estimated value of σ^2A was higher than its σ^2D, which indicated the predominance of additive gene action as the ratio of σ^2A/σ^2D was more than unity, while rest of the traits showed preponderance of non-additive gene action. Further, the estimates of average degree of dominance ($\sqrt{(\sigma^2 D / \sigma^2 A)}$) showed over dominance for number of effective tillers (1.41), spike length (1.41), awn length (1.21), number of grains per spike (1.62), chlorophyll content (1.23), stomatal conductance (1.37) and proline content (1.87) while for traits like thousand grain weight (0.94) and harvest index (0.91) were reported complete dominance. Whereas partial dominance were observed for days to 50% flowering (0.35), days to maturity (0.74), plant height (0.81) and grain yield per plant (0.86) under rainfed condition (2011-12). Similarly, days to 50% flowering (1.23), plant height (2.03), number of grains per spike (1.19), harvest index (2.21), chlorophyll content (1.32) and stomatal conductance (1.18) exhibited over dominance under rainfed condition (2012-13) whereas, days to 50% flowering (1.50), number of effective tillers (1.28), spike length (1.20), awn length (5.73), number of grains per spike (1.32), harvest index (1.41), grain yield per plant (1.46), stomatal conductance (1.36) and proline content (1.61) revealed over dominance under irrigated condition

(2012-13). Moreover, number of grains per spike and stomatal conductance affirmed over dominance and days to maturity revealed partial dominance over the environmental conditions (rainfed 2011-12, 2012-13 and irrigated 2012-13).

4.6 Proportional contribution of lines, testers and their interaction to total variance

Proportional contribution of lines, testers and line x testers for various characters are presented in Table 4.7.

4.6.1 Contribution of lines to total variance

The proportional contribution of lines to total variance was observed maximum for days to 50 % flowering (64.09%) followed by grain yield per plant (62.65%), days to maturity (58.72%), harvest index (56.02%), thousand grain weight (52.51%) and plant height (46.04) under rainfed condition during 2011-12. Days to 50 % flowering (50.31%), chlorophyll content (49.48%), days to maturity (46.97%) and awn length (45.15%) showed greater proportional contribution of lines to total variance under irrigated condition during 2012-13 while number of grains per spike (54.05%) revealed higher proportional contribution of lines under rainfed condition during 2012-13.

4.6.2 Contribution of testers to total variance

The contribution of testers towards sum of square due to crosses was less than 50% for all the traits studied. It is apparent from the table 4.9 that the contribution of testers was maximum for plant height (55.04%) under irrigated condition (2012-13) while for days to maturity (56.83%), awn length (52.82%), grain yield per plant (52.73%), proline content (48.92%), number of effective tillers (47.28%), days to 50 % flowering (45.94%) and thousand grain weight (36.99%) revealed higher proportional contribution of testers to total variance under rainfed condition (2012-13).

4.6.3 Contribution of line x tester to total variance

The proportional contribution of line x tester was observed highest for proline content (69.58%) followed by spike length (65.21%), number of grains per spike (61.72%), stomatal conductance (58.17%), number of effective tillers (56.19%), awn length (54.80%) and chlorophyll content (51.25%) under rainfed condition (2011-12). Further, number of grains per spike (79.11%), stomatal conductance (75.25%), harvest index (74.86%), number of effective tillers (66.64%), proline content (64.97%), grain yield per plant (63.82%), spike length (62.93%) and thousand grain weight (40.27%) showed higher proportional contribution of line x tester than line and tester under irrigated condition (2012-13) while, harvest index (73.35%), plant height (69.18%), stomatal conductance (64.49%), chlorophyll content (50.91%) and spike length (42.04%) revealed greater proportional contribution of line x tester to total variance than line and tester under rainfed condition (2012-13). In general, the proportional contribution of line × tester interaction towards sum of square of crosses contributed more than line and tester for most of the traits studied over the environment (Table 4.9).

4.7 Estimation of general means, heritability and expected genetic advance

The mean performances of 6 lines, 4 testers and their 24 crosses for all the traits were presented in appendix III, IV and V. The general mean, heritability (narrow sense) and expected genetic advance of individual traits have been presented in Tables 4.8.1, 4.8.2 and 4.8.3. The estimates of heritability are categorized as High (>30%), Moderate (>10% and <30%) and Low (<10%). In general, all the traits exhibited moderate to high heritability.

Under rainfed condition of 2011-12, plant height (58.50%) showed highest narrow sense heritability followed by grain yield per plant (54.97%), harvest index (52.87%), thousand grain weight (52.30%), days to 50% flowering (43.17%), days to maturity (38.72%), awn length (36.22%), chlorophyll content (33.37%) and number of effective tillers (32.19%) (Table 4.8.1). While remaining traits, stomatal conductance (27.79%), number of grains per spike (26.80%), spike length (26.23%) and proline content (13.54%) exhibited moderate narrow sense heritability. The estimations of heritability are more meaningful when it estimated along with genetic gain. The grain yield per plant (41.06%) revealed highest value of genetic advance as per cent of mean followed by proline content (29.24%), thousand grain weight (23.92%), harvest index (17.36%), number of grains per spike (16.19%), number of effective tillers (15.38%), plant height (12.80%), awn length (10.57%) and spike length (10.44%).

It is apparent from table 4.8.2 that the thousand grain weight (61.09%) revealed highest narrow sense heritability followed by days to maturity (55.81%), awn length (52.96 %), days to 50% flowering (47.78%), number of effective tillers (45.54%), grain yield per plant (44.98%), spike length (40.86%), proline content (38.54%) and number of grains per spike (32.42%) under rainfed condition (2012-13) while harvest index (73.68%), number of grains per spike (64.55%), days to maturity (60.85%), plant height (55.88%), thousand grain weight (48.30%), stomatal conductance (44.67%), days to 50% flowering (36.42%), chlorophyll content (35.42%) and proline content (31.98%) revealed high to moderate heritability under irrigated condition (2012-13) (Table 4.8.3). Moreover, grain yield per plant (34.53%) revealed highest and harvest index (1.55%) lowest value of genetic advance as per cent of mean under rainfed condition (2012-13) while thousand grain weight (12.12%) scored highest and awn length (1.48%) lowest genetic advance as per cent of mean under irrigated condition (2012-13).

4.8 Extent of heterosis

The magnitude of heterosis in per cent over better parent (heterobeltiosis) and over standard check (standard heterosis) in 24 F_1's obtained from line x tester analysis for 13 traits were estimated in moisture stress (rainfed) conditions during *rabi* 2011-2012 & 2012-13 and moisture non-stress (irrigated) condition during *rabi* 2012-13 (Tables 4.9.1, 4.9.2 and 4.9.3 respectively). K 603, the variety released during year 2000 was taken as standard check. The higher mean of the parent and F_1

was considered better for most of the traits except days to 50% flowering, days to maturity, plant height and stomatal conductance. Manifestation of heterosis was found in both positive and negative directions. In case of better parent heterosis and standard heterosis, only positive values are described for all the traits except, days to 50% flowering, days to maturity, plant height and stomatal conductance for which negative values (desirable ones) have been taken for consideration.

4.8.1 Days to 50% flowering

Since earliness with high yield is desirable, crosses with negative heterosis for flowering would be considered as desirable. The magnitude of heterosis was observed significant in 15 crosses over better parent and 26 crosses over standard check. The maximum significant negative heterosis over better parent was recorded for BCU 4927 x Karan 16 (-13.62) followed by BCU 4925 x K 603 (-9.96), BCU 4925 x Lakhan (-9.13) and BCU 4927 x Lakhan (-8.17) under rainfed condition during 2011-12 while BCU 4925 x RD 2035 (-13.72) during 2012-13. Similarly, BCU 4932 x Lakhan (-11.11) and BCU 4932 x K 603 (-10.82) showed significant negative heterosis over better parent under irrigated condition (2012-13). On the other hand, BCU 4922 x Lakhan (-17.18) and BCU 4956 x RD 2035 (-13.22) showed significant negative standard heterosis per cent for days to 50% flowering under rainfed condition (2012-13) while BCU 4910 x K 603 (-11.30), BCU 4925 x Lakhan (-9.61) and BCU 4932 x RD 2035 (-9.57) under irrigated condition (2012-13).

4.8.2 Days to maturity

The magnitude of heterosis was recorded significant in 21 crosses over better parent and 28 crosses over standard check. The highest significant negative heterosis per cent over better parent was observed for BCU 4927 x Karan 16 (-8.78) followed by BCU 4925 x Lakhan (-7.41), BCU 4925 x K 603 (-7.41), BCU 4956 x K 603 (-7.16) and BCU 4927 x RD 2035 (-6.80) under rainfed condition (2011-12). Similarly, BCU 4927 x Lakhan (-7.90) and BCU 4956 x K 603 (-6.51) showed significant negative heterosis over better parent under rainfed condition (2012-13) while BCU 4932 x K 603 (-7.58) under irrigated condition of 2012-13. Further, under rainfed condition (2011-12) BCU 4922 x Lakhan (-8.54) showed significant negative standard heterosis for days to maturity. BCU 4932 x K 603 (-9.45), BCU 4922 x K 603 (-9.15) and BCU 4956 x RD 2035 (-8.54) exhibited significant negative standard heterosis under rainfed condition (2012-13) while BCU 4932 x Lakhan (-9.12) and BCU 4910 x K 603 (-6.99) under irrigated condition (2012-13).

4.8.3 Plant height

Thirty one crosses exhibited significant heterobeltiosis and 24 crosses showed significant economic heterosis for plant height. Promising crosses exhibiting heterosis over standard check, in order of merit were, BCU 4956 x Lakhan (-21.19%), BCU 4927 x Lakhan (-20.97%) and BCU 4956 x RD 2035 (-19.22%) under rainfed condition (2011-12). Similarly, BCU 4932 x Karan 16 (-31.28) showed significant heterosis over standard check under rainfed condition and BCU 4925 x K 603 (-18.49) under irrigated condition (2012-13). On the other hand, BCU 4956 x Lakhan (-31.65%), BCU 4927 x Lakhan (-31.46 %) and BCU 4922 x Lakhan (-27.02%) were observed as promising crosses for heterobeltiosis under rainfed condition (2011-12). Further, BCU 4922 x RD 2035 revealed significant heterosis over better parent under both rainfed (-25.99) and irrigated (-13.95) conditions during 2012-13.

4.8.4 Number of effective tillers

The significant heterosis was observed in most of the crosses over standard check and better parent. The magnitude of heterosis over standard check for top three crosses were BCU 4910 x Lakhan (45.05%), BCU 4925 x Karan 16 (43.53%) and BCU 4922 x Lakhan (40.80%) under rainfed condition during 2011-12 while BCU 4922 x Lakhan (53.48) during 2012-13. Similarly BCU 4956 x K 603 (77.44), BCU 4932 x Lakhan (75.09) and BCU 4922 x Lakhan (64.73) were in order of merit, exhibiting significant heterosis over standard check under irrigated condition during 2012-13. Further the crosses BCU 4925 x Karan 16 (23.29 %) and BCU 4910 x Karan 16 (18.18%) showed positive and significant heterosis over better parent under rainfed condition of 2011-12 and BCU 4956 x Karan 16 (93.56), BCU 4922 x Lakhan (91.70) and BCU 4910 x Lakhan (89.05) under rainfed condition of 2012-13 while a

BCU 4922 x Karan 16 (90.00), BCU 4922 x Lakhan (89.92) and BCU 4956 x K 603 (89.64) under irrigated condition during 2012-13.

4.8.5 Spike length

The magnitude of heterosis was registered significant in 20 crosses over better parent and 17 crosses over standard check for spike length. Top three heterotic crosses BCU 4910 x Karan 16 (36.08), BCU 4910 x K 603 (35.78) and BCU 4925 x RD 2035 (34.91) showed significant positive heterosis (%) for spike length over standard check while BCU 4910 x Karan 16 (36.08) and BCU 4925 x Karan 16 (21.74) over better parent under rainfed condition (2011-12). Similarly BCU 4925 x Karan 16 (38.88) and BCU 4922 x Karan 16 (36.16) were revealed significant positive heterosis over standard check while BCU 4925 x Karan 16 (49.86) and BCU 4922 x Karan 16 (40.59) over better parent under rainfed condition (2012-13). Further, under irrigated condition during 2012-13, BCU 4932 x K 603 (28.74) showed significant positive heterosis over standard check while BCU 4932 x K 603 (33.59), BCU 4925 x RD 2035 (29.79) and BCU 4927 x Karan 16 (25.65) over better parent for spike length.

4.8.6 Awn length

The magnitude of heterosis revealed significant for most of the crosses over standard check and better parent. Only one cross BCU 4910 x Karan 16 (16.98) was showed positive significant heterobeltiosis for awn length under rainfed condition (2011-12) while BCU 4910 x Karan 16 (45.53%), BCU 4925 x Karan 16 (45.25%) and BCU 4922 x K 603 (39.39%) were the top three economic heterotic crosses. Similarly BCU 4932 x Lakhan (59.33), BCU 4922 x Lakhan (58.60) and BCU 4956 x K 603 (46.26) were top three promising crosses exhibiting heterosis over standard check whereas BCU 4922 x Lakhan (33.22) and BCU 4932 x Lakhan (31.19) over better parent under rainfed condition (2012-13). Further, BCU 4932 x K 603 (56.51), BCU 4927 x Lakhan (48.05) and BCU 4932 x Lakhan (47.83) were top three promising heterotic crosses revealed heterosis over standard check while BCU 4932 x

K 603 (40.12) showed positive significant heterobeltiosis for awn length under irrigated condition (2012-13).

4.8.7 Number of grains per spike

The magnitude of heterosis was observed significant for almost all the crosses over standard check as well as better parent. Although, the magnitude of economic heterosis was significant it was in negative direction under both the environmental conditions. However, BCU 4927 x RD 2035 (58.79), BCU 4910 x Karan 16 (28.87) and BCU 4927 x Karan 16 (26.33) were top three crosses showed significant positive heterosis (%) over better parent under rainfed condition (2011-12).

4.8.8 Thousand grain weight

The magnitude of heterosis was registered highly significant for most of the crosses over better parent as well as standard check. Among these top three crosses having significant positive heterosis (%) over standard check were BCU 4932 x Karan 16 (96.19), BCU 4922 x K 603 (92.24) and BCU 4925 x Karan 16 (91.25) while top three crosses over better parent were BCU 4925 x Karan 16 (23.86), BCU 4922 x K 603 (17.38) and BCU 4932 x Karan 16 (11.52) under rainfed condition (2011-12). Similarly, BCU 4932 x Lakhan (47.32), BCU 4956 x K 603 (46.86) and BCU 4956 x Lakhan (43.87) exhibited significant positive heterosis over standard check in order of merit while BCU 4956 x K 603 (24.77), BCU 4932 x Lakhan (18.10) and BCU 4956 x RD 2035 (17.78) were observed with significant heterobeltiosis under rainfed condition (2012-13). Moreover, BCU 4956 x Lakhan (58.56), BCU 4925 x Lakhan (51.34) and BCU 4932 x K 603 (49.82) were showed significant positive economic heterosis in order of merit, for thousand grain weight whereas, BCU 4956 x Lakhan (37.99), BCU 4932 x K 603 (34.09) and BCU 4956 x K 603 (29.68) exhibited heterobeltiosis under irrigated condition (2012-13).

4.8.9 Harvest index

Promising crosses exhibiting positive heterosis over standard check were observed and in order of merit top three crosses were BCU 4922 x Karan 16

(62.48%), BCU 4925 x Karan 16 (59.18%) and BCU 4922 x RD 2035 (56.05%) and top three crosses for heterobeltiosis were BCU 4925 x RD 2035 (29.45%), BCU 4922 x Karan 16 (15.28%) and BCU 4925 x Karan 16 (14.35%) under rainfed condition (2011-12). During 2012-13 BCU 4927 x K 603 (25.74) and BCU 4925 x K 603 (23.83) exhibited positive significant heterosis over standard check and better parent with different values [BCU 4927 x K 603 (24.68) and BCU 4925 x K 603 (22.78)] BCU 4922 x Karan 16 (21.93) and BCU 4910 x K 603 (21.54) revealed positive significant economic heterosis under irrigated condition (2012-13).

4.8.10 Grain yield per plant

The positive and significant heterosis was observed in most of the crosses over standard check as well as better parent for grain yield per plant (Tables 4.9.1, 4.9.2 and 4.9.3). The maximum per cent heterosis over standard check was observed in BCU 4922 x K 603 (97.40) followed by BCU 4910 x Lakhan (95.80) and BCU 4932 x K 603 (89.50) while the crosses BCU 4922 x K 603 (52.02), BCU 4932 x Karan 16 (51.77) and BCU 4925 x Karan 16 (27.10) showed positive significant heterosis over better parent under rainfed condition (2011-12). Similarly BCU 4922 x Lakhan (94.86), BCU 4925 x K 603 (83.32) and BCU 4932 x Lakhan (77.81) revealed positive significant economic heterosis while, BCU 4925 x K 603 (95.81) BCU 4922 x Lakhan (95.12) and BCU 4932 x K 603 (91.02) exhibited heterobeltiosis in order of merit under rainfed condition (2012-13). Further, during irrigated condition 2012-13, BCU 4932 x Lakhan (71.27), BCU 4925 x K 603 (47.15) and BCU 4925 x Lakhan (42.98) exhibited maximum per cent economic heterosis whereas BCU 4910 x RD 2035 (72.17) BCU 4956 x Karan 16 (57.35) and BCU 4925 x K 603 (45.65) revealed positive significant heterobeltiosis for grain yield per plant.

4.8.11 Chlorophyll content

The magnitude of heterosis was observed highly significant in 17 crosses over better parent and 19 crosses over standard check. The crosses, BCU 4932 x RD 2035 (27.53), BCU 4922 x Karan 16 (27.14) and BCU 4922 x K 603 (20.89) showed significant positive heterosis (%) over standard check under rainfed condition

(2011-12). Further, during rainfed 2012-13 BCU 4932 x K 603 (11.63) and BCU 4925 x Karan 16 (11.55) revealed maximum per cent economic heterosis whereas BCU 4922 x Karan 16 (28.58), BCU 4925 x Karan 16 (28.42) and BCU 4956 x Karan 16 (23.68) were scored as top three crosses exhibited significant positive heterobeltiosis. Similarly BCU 4956 x K 603 (32.82), BCU 4956 x Karan 16 (29.22) and BCU 4956 x Lakhan (28.11) in order of merit were observed as top three crosses exhibited economic heterosis while BCU 4956 x K 603 (23.70) and BCU 4956 x Lakhan (19.31) showed significant positive heterobeltiosis under irrigated condition (2012-13).

4.8.12 Stomatal conductance

The magnitude of heterosis was observed significant in 16 crosses over better parent and 10 crosses over standard check. The crosses with negative heterosis for stomatal conductance were considered as desirable under moisture stress (rainfed) condition. The maximum significant negative heterosis over better parent was observed for BCU 4922 x K 603 (-14.61%) followed by BCU 4932 x Karan 16 (-14.48) and BCU 4932 x RD 2035 (-13.14) whereas the crosses BCU 4922 x K 603 (-9.52%) and BCU 4932 x Karan 16 (-8.15%) showed significant negative standard heterosis for stomatal conductance under rainfed condition (2011-12). Further, only BCU 4922 x Lakhan (-8.47) showed significant negative economic heterosis while BCU 4922 x Lakhan (-13.93) and BCU 4925 x Lakhan (-13.17) revealed significant negative heterosis over better parent under rainfed condition (2012-13). On the other hand, during irrigated condition 2012-13, BCU 4927 x RD-2035 (12.72), BCU 4910 x Karan 16 (11.34), BCU 4956 x Karan 16 (10.61) and BCU 4922 x Lakhan (10.61) exhibited significant positive economic heterosis whereas BCU 4927 x RD-2035 (8.31), BCU 4910 x Karan 16 (7.31) and BCU 4922 x Lakhan (6.61) revealed maximum significant positive heterobeltiosis for stomatal conductance.

4.8.13 Proline content

The magnitude of heterosis was observed significant in 13 crosses over better parent and 19 crosses over standard check. The top promising crosses exhibiting heterosis over standard check, in order of merit were, BCU 4927 x Karan 16 (34.29%), BCU 4956 x K 603 (32.63%) and BCU 4932 x Karan 16 (31.41%) and for heterobeltiosis the top three crosses were BCU 4927 x Lakhan (19.59%), BCU 4932 x Karan 16 (17.03%) and BCU 4925 x Karan 16 (11.62 %) rainfed condition (2011-12). Similarly, BCU 4925 x Lakhan (49.17), BCU 4932 x Lakhan (39.91) and BCU 4927 x RD-2035 (33.99) revealed positive significant economic heterosis while, BCU 4927 x RD-2035 (32.98) and BCU 4925 x Lakhan (19.15) revealed maximum per cent heterobeltiosis under rainfed condition (2012-13). On the other hand top three crosses BCU 4956 x RD 2035 (21.56), BCU 4922 x Lakhan (21.36) and BCU 4910 x K 603 (20.74) exhibited significant positive economic heterosis whereas BCU 4910 x Lakhan (25.23), BCU 4910 x RD 2035 (25.13) and BCU 4932 x RD 2035 (21.28) showed significant positive heterobeltiosis for proline content under irrigated condition (2012-13).

4.9 Estimate of gene actions through generation mean analysis

The generations mean analysis for selected cross combinations was done under two environments i.e. moisture non- stress (irrigated) and moisture stress (rainfed) conditions in *rabi* 2012-13 (Table 4.10 and 4.11, respectively). Besides additive and dominance, this analysis provides the information about the epistasis which was not possible in Line × Tester analysis. It is important to identify and estimate non-allelic interactions which could otherwise inflate the measures of additive and dominance components. The generation mean analysis is one of most appropriate methods of genetic analysis for quantitative traits, which provide suitable information about the relative importance of the average effects of the genes, dominance effects and effects due to non-allelic interactions in determining genotypic values of the individuals and consequently mean genotypic values of families and generations.

For generation mean analysis, the diverse parents for each trait were selected such as, BCU 4910 and Lakhan for days to 50% flowering and days to maturity, BCU 4922 and K 603 for plant height, BCU 4927 and Lakhan for number of effective tillers, BCU 4956 and Karan 16 for spike length and grain yield per plant, BCU 4956 and K 603 for awn length and harvest index, BCU 4910 and K 603 for number of grains per spike, BCU 4910 and RD 2035 for thousand grain weight, BCU 4910 and Karan 16 for chlorophyll content, BCU 4925 and RD 2035 for stomatal conductance and BCU 4956 and RD 2035 for proline content on the basis of mean performance of parents in Line x Tester analysis during moisture stress (rainfed) condition under *rabi* 2011-2012.

4.9.1 Scaling test

The means of parents, F_1s, F_2s, B_1s and B_2s of ten selected crosses were subjected to scaling tests following Mather (1949) and Cavalli (1952). The estimates on the scales under two environments i.e. moisture non- stress (irrigated) and moisture stress (rainfed) conditions during *rabi* 2012-13 are presented in Table 4.11 and 4.12, respectively. The 'A' and 'B' scaling tests provide evidence on all the three types of epistasis, additive × additive (*i*), additive × dominance (*j*) and dominance × dominance (*l*)**.** The 'C' and 'D' scales exhibit exclusively '*l*' and '*i*' types of interactions, respectively. Epistasis was observed in all the ten crosses as it is evident from the significance of one or more of the four scales (A, B, C and D scales) for all the traits under study. To validate the results of A, B, C and D scaling test, joint scaling test as suggested by Cavalli (1952) was also performed. The joint scaling test also revealed presence of non-allelic interactions in all the ten crosses for all the traits.

4.9.2 Gene effects

The adequacy of additive dominance model was studied following the A, B, C and D scaling tests of Mather (1949) and the joint scaling test of Cavalli (1952). The crosses which did not satisfy adequacy of scales a digenic epistatic model was fitted and it was subjected to six-parameter model of Hayman (1958) and Jinks and Jones (1958) as well as to that of weighted least square method of Cavalli (1952) as described by Mather and Jinks (1982) for the estimation of genetic parameters (*m*, *d*, *h*, *i*, *j* and *l*) for individual crosses. The estimates of gene effects for thirteen characters in ten crosses of barley are particularised trait wise below.

4.9.2.1 Days to 50 per flowering

Significant differences were observed among the generation for days to 50 per flowering in the cross BCU 4910 x Lakhan. The joint scaling tests and A, B, C and D scaling tests were found to be significant for this trait in both the environments i.e. moisture non- stress (irrigated) and moisture stress (rainfed). In rainfed condition both additive (*d*) and dominance (*h*) gene effects were positively significant but dominance gene effect (10.33) was higher than additive effect (3.33). Whereas, additive component (-5.00) was negatively significant in irrigated condition. In general, the magnitude of the dominance component (*h*) was greater (10.33) than the additive and epistatic component (*i*, *j* and *l*) under rainfed condition.

In case of non allelic interactions, only additive × dominance (*j*) gene interaction (-6.66) was negatively significant under irrigated condition whereas additive × additive (5.33) type of gene interaction was positively significant in rainfed environment. Chi-square value of this cross was significant showing adequacy of fitness of six-parameter model, under sequential model fitting scheme.

4.9.2.2 Days to maturity

The same cross, BCU 4910 x Lakhan was evaluated for days to maturity also and it revealed significant differences between the generations. The said cross was observed to be interacting both A, B, C and D scaling and joint scaling tests. After elimination of non-significant component either one or all the three of *i*, *j* and *l* under sequential fitting model scheme the above cross was found to be fit for six-parameter models.

In rainfed condition both additive (*d*) and dominance (*h*) gene effects were positively significant but dominance gene effect (11.00) was higher than additive effect (4.33). Whereas, only dominance (*h*) gene effect (29.33) was positively significant and additive component (-2.00) was negatively significant in irrigated condition. On the other hand, the magnitude of dominance × dominance (*l*) gene interaction (-46.66 and -11.33) was negatively significant and larger than the dominance component (*h*) and additive component (*d*) under both the environments. There were positive significant values 26.66 and 6.00 observed for additive × additive (*i*) type of gene interaction under irrigated and rainfed environments, respectively. The above cross exhibited significant and apposite sign of '*h*' and '*l*' component which indicated the presence of duplicate type of epistasis.

4.9.2.3 Plant height

The cross BCU 4922 x K 603 was evaluated for plant height which revealed significant differences between the generations. This cross was found to be interacting following A, B, C and D scaling tests and joint scaling tests. BCU 4922 x K 603 showed positive significant additive (*d*) gene effect (4.33 and 2.27) under both the environments whereas dominance component (*h*) was negatively significant (-14.25) under rainfed environment only.

In case of non allelic interactions, additive × dominance (*j*) gene interaction (3.23) was positively significant while the magnitude of dominance × dominance (*l*) gene interaction (-36.16) and additive × additive (*i*) type of gene interaction (-21.87) were negatively significant under irrigated and rainfed environments, respectively. The magnitude of additive × dominance (*j*) gene interaction (11.62) and dominance × dominance (*l*) gene interaction (21.57) were positively significant and cross exhibited duplicate epistasis for the above trait under rainfed environment.

4.9.2.4 Number of effective tillers

The significant differences were observed between the generations in the cross BCU 4927 x Lakhan for number of effective tillers. This cross was figured out as interacting following A, B, C and D scaling tests in rainfed while only B and D scaling tests under irrigated environment and the cross was also found interacting under joint scaling tests in both the environments. Highly significant variation was noticed in F_2 population.

The magnitude of the dominance component (*h*) was positively significant (13.79) and was larger than additive component (*d*) and also epistasis components (*i*, *j* and *l*) under irrigated environment. The additive × additive (*i*) type of gene effect (7.53) was positively significant while the dominance × dominance component (-13.18) was found to be negatively significant in irrigated environment. Duplicate type of epistasis was found to be present as the sign of '*h*' and '*l*' were opposite in direction.

4.9.2.5 Spike length

The cross BCU 4956 x Karan 16 was evaluated for spike length which revealed significant differences between the generations. The cross BCU 4956 x Karan 16 was figured out as interacting following B, C and D scaling tests in irrigated environment and A, B, C and D scaling tests in rainfed environment. At the same time, the cross was also found interacting under joint scaling tests. The F_2 population was exhibited highly significant variation for this trait. The estimate of gene effects revealed that dominance (*h*) and epistatic gene effects (*i*, *j* and *l*) were significant for the cross under both the environments.

In irrigated environment, additive component (0.34) reported positively significant whereas epistatic component i.e. additive × additive (*i*) type of gene effect (-1.37) and additive × dominance (*j*) gene interaction (-1.16) were observed significantly negative. Further, in rainfed environment, additive (*d*) gene effect (-0.54) and dominance (*h*) gene effect (-3.73) were reported negatively significant while only dominance × dominance (*l*) gene interaction (4.89) was positively significant and duplicate type of epistasis was found to be present as the sign of '*h*' and '*l*' were opposite in direction.

4.9.2.6 Grain yield per plant

The same cross BCU 4956 x Karan 16 was evaluated for grain yield per plant which revealed significant differences between the generations. The cross BCU 4956 x Karan 16 was figured out as interacting following B, C and D scaling tests in irrigated environment and A, B, C and D scaling tests in rainfed environment. At the same time, the cross was also found interacting under joint scaling tests. The F_2 population was exhibited highly significant variation for grain yield per plant.

In irrigated environment, additive component (2.15) was observed positively significant while dominance (*h*) component (-13.15) was negatively significant whereas epistatic component i.e. additive × dominance (*j*) gene interaction 2.73) and dominance × dominance (*l*) type of gene effect (28.64) were observed positively significant and duplicate type of epistasis was found to be present as the sign of '*h*' and '*l*' were opposite in direction. Moreover, in rainfed environment, dominance (*h*) gene effect (8.44) was positive and larger than additive (*d*) gene effect (-4.95) while, only additive × additive (*i*) gene interaction (3.30) was positively significant.

4.9.2.7 Awn length

The significant differences were observed in the cross BCU 4956 x K 603 between the generations. This cross was figured out as interacting following A, B, C and D scaling tests in irrigated environment and C and D scaling tests in rainfed environment, however, this cross was also found interacting under joint scaling tests. Highly significant variation was observed in F_2 population. The magnitude of dominance (*h*) component (8.95 and 2.60) was reported positively significant and higher than additive component (*d*) under both the environments. In the event of non allelic interactions, additive × additive (*i*) gene interaction (2.28 and 4.96) was positively significant and duplicate type of epistasis was found to be present as the sign of '*h*' and '*l*' were opposite in direction under both the environments.

4.9.2.8 Harvest index

The same cross BCU 4956 x K 603 was evaluated for harvest index which revealed significant differences between the generations. This cross also figured out as interacting following C and D scaling tests in irrigated environment and B, C and D scaling tests in rainfed environment. Simultaneously, this cross was also found interacting under joint scaling tests. The magnitude of additive (*d*) component (4.38) as well as, dominance (*h*) component (29.77) were observed positively significant in irrigated environment while dominance (*h*) component (-19.30) was negatively significant under rainfed environment. In case of non allelic interactions, only additive × additive (*i*) gene interaction (24.88) was positively significant and duplicate type of epistasis was found to be present under irrigated environment.

4.9.2.9 Number of grains per spike

For number of grains per spike, significant differences were observed between the generations. The cross BCU 4910 x K 603 was sorted out as interacting following A and B scaling tests in irrigated environment and A, B, and C scaling tests in rainfed environment. Simultaneously, this cross was also found interacting under joint scaling tests. The magnitudes of additive (*d*) component as well as dominance (*h*) component were observed negatively significant under both the environments. The dominance × dominance (*l*) gene interaction (8.17 and 20.29) was larger than additive × dominance (*j*) gene interaction (6.10 and 13.10) under both the environments. Duplicate type of epistasis was found to be present as the sign of '*h*' and '*l*' were opposite in direction.

4.9.2.10 Thousand grain weight

BCU 4910 x RD 2035 was evaluated for thousand grain weight which revealed significant differences between the generations. This cross figured out as interacting following A, B, C and D scaling tests under irrigated environment and A and D scaling tests under rainfed environment. Meanwhile, this cross was also found interacting under joint scaling tests. F_2 population revealed highly significant variation.

In irrigated environment, dominance (*h*) component (23.57) exhibited positively significant and higher than additive (*d*) component (12.00) alongwith epistatic component i.e. additive × additive (*i*) type of gene effect (11.67) additive × dominance (*j*) gene interaction (5.61) which were observed positively significant. Moreover, in rainfed environment, additive (*d*) gene effect (3.77) and dominance × dominance (*l*) gene interaction (13.07) was positively significant. As the sign of '*h*' and '*l*' were opposite in direction duplicate type of epistasis was reported for thousand grain weight.

4.9.2.11 Chlorophyll content

For chlorophyll content, significant differences were observed between the generations. The cross BCU 4910 x Karan 16 was sorted out as interacting following A, B, C and D scaling tests under irrigated environment and A, B, and C scaling tests under rainfed environment. Simultaneously, this cross was also found interacting under joint scaling tests. In irrigated environment, additive (*d*) component (7.33) and epistatic component i.e. additive × dominance (*j*) gene interaction (11.35) were observed significant and positive. Complementary type of epistasis was found to be present as the sign of '*h*' and '*l*' were in same direction. Moreover, in rainfed environment, only dominance (*h*) component (5.33) was positively significant. As the sign of '*h*' and '*l*' were opposite in direction duplicate type of epistasis was reported.

4.9.2.12 Stomatal conductance

BCU 4925 x RD 2035 was evaluated for stomatal conductance which revealed significant differences between the generations. This cross was sorted out as interacting following A, B and D scaling tests in both the environments. Also, this cross was found interacting under joint scaling tests. F_2 population revealed highly significant variation. The magnitude of dominance (*h*) component (-376.63 and -327.50) was reported negatively significant in both the environments. In the event of non allelic interactions, dominance × dominance (*l*) gene interaction (660.47 and 695.00) was observed positively significant under both the environments. As the sign of '*h*' and '*l*' were opposite in direction duplicate type of epistasis was reported.

4.9.2.13 Proline content

The significant differences were observed in the cross BCU 4956 x RD 2035 between the generations. This cross was figured out as interacting following C scaling tests in irrigated environment and A, C and D scaling tests in rainfed environment. Also, this cross was found interacting under joint scaling tests. Highly significant variation was observed in F_2 population. After elimination of non-significant component either one or all the three of *i*, *j* and *l* under sequential fitting model scheme the above cross was found to be fit for six-parameter model. In irrigated environment, additive (*d*) component (0.15) was observed positively significant. Moreover, in rainfed environment, in the event of non allelic interactions, only dominance × dominance (*l*) gene interaction (2.01) was observed positively significant. As the sign of '*h*' and '*l*' were opposite in direction duplicate type of epistasis was reported.

4.10 Studies on transgressive segregants and drought tolerant recombinants in F_2 generation

The 10 cross combinations selected for generations mean analysis were grown under two environments i.e. moisture non- stress (irrigated) and moisture stress (rainfed) conditions under *rabi* 2012-13. Data recorded on grain yield per plant relating to 10 F_2's originating from these crosses were subjected for screening transgressive segregants and drought tolerant recombinants.

4.10.1 Transgressive segregants

The number of F_2 segregants showing grain yield per plant higher than both the parents as well as the standard check K 603 were scored cross wise (Table 4.12). The crosses, such as, BCU 4910 x Lakhan (7), BCU 4910 x K 603 (15), BCU 4922 x K 603 (18), BCU 4925 x RD 2035 (14), BCU 4956 x K 603 (20) and BCU 4956 x RD 2035 (13) yielded good number of transgressive segregants under irrigated condition whereas BCU 4910 x K 603 (15), BCU 4922 x K 603 (17), BCU 4925 x RD 2035 (8) and BCU 4956 x RD 2035 (7) yielded promising transgressive segregants under rainfed condition. More interestingly, crosses BCU 4910 x K 603 and BCU 4922 x K 603 were promising under both the conditions. The performance of certain promising transgressive segregants in F_2 generation showing grain yield per plant higher than both the parents as well as standard check K 603, along with a few important traits such as, number of effective tillers, thousand grain weight, harvest index, stomatal conductance, chlorophyll content, proline content are presented in Tables 4.14 and 4.15.

In general, transgressive segregants in the both the conditions, revealed high number of effective tillers, thousand grain weight and harvest index. The next important trait associated with transgressive segregants popped up to be proline content in both the conditions. The magnitude of number of effective tillers of transgressive segregants were discernible ranging from 10 to 20 and 6 to 19 as compared to its values of 8.45 and 6.63 in standard check (K 603) in irrigated and rainfed conditions, respectively. While in case of, thousand grain weight it ranged from 42.10 to 64.70 and 32.30 to 67.20 with respect to its values of 45.87 and 51.13 in K 603 under irrigated and rainfed conditions. The magnitude of harvest index of transgressive segregants were appreciable ranging from 41.25 to 75.13 and 34.30 to 86.27 as compared to its values of 55.91 and 53.85 in standard check (K 603) in irrigated and rainfed conditions, respectively.

The proline content of transgressive segregants were noticeable ranging from 1.35 to 2.13 mg/g and 1.58 to 3.55 mg/g as compared to standard check (K 603) having 1.48 and 2.41 mg/g under irrigated and rainfed conditions, respectively. The percentage increase in gain yield over standard check (K 603) ranged from 6.04 to 49.82 under irrigated conditions whereas it ranged from 7.38 to 58.20 under rainfed environment.

4.10.2 Screening for drought tolerant recombinants

Data recorded on grain yield per plant relating to 10 F_2's originating from a selected crosses under two environments i.e. moisture non- stress (irrigated) and moisture stress (rainfed) conditions in *rabi* 2012-13 were utilized to calculate the drought susceptibility index(S) (Table 4.16) .The yield under rainfed conditions (Y_d) and yield under irrigated i.e. yield potential (Y_p) were utilized to calculate drought susceptibility index (S). The selection was based on Y_d values in the first instances, which were followed by and supported by the data of drought susceptibility index (S) and geometric mean (GM) to identify drought tolerant cross.

The cross BCU 4956 x K 603 was most desirable cross from which the selection of plants gave highest mean yield under rainfed (Y_{d} = 17.21 g/plant) and maximum geometric mean (GM = 18.93 g/plant). It ranked 1st for Y_p (20.82 g/plant) and 5th for drought susceptibility index (S = 0.72). The cross BCU 4922 x K 603 revealed high mean yield under rainfed (Y_{d} = 14.89 g/plant), 3rd rank for Y_p (18.21 g/plant), higher geometric mean (GM = 16.47 g/plant) and 6th rank for drought susceptibility index (S = 0.76) The cross/ genotypes which showed least drought susceptibility index value (<1) is identified as drought tolerant/ resistant and therefore, it might be concluded on the basis of Y_d, Y_p, GM and S values that plant derived from the cross BCU 4956 x K 603 and BCU 4922 x K 603 were drought tolerant.

The qualitative traits such as leaf rolling and stay green were recorded visually in field and presented in Table 4.17. It is apparent from the table that the most of the genotypes/crosses revealed leaf rolling scale 2 and 3 which confirmed the interrelation between leaf rolling and water deficit. Leaf rolling is the symptom of drought tolerance. With the onset of drought the symptoms of leaf rolling started and plants showed mortality with increase in drought severity. Hence most of the genotypes showed drought tolerance/resistant on the basis of leaf rolling scale. Similarly, most of the genotypes/crosses also revealed stay green till maturity (Table 4.17).

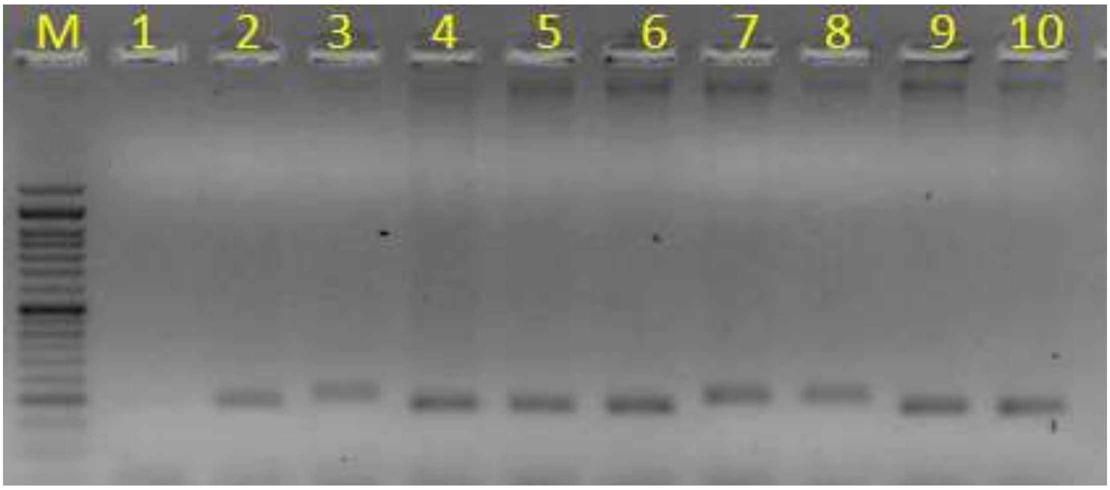

Fig 4.1: **Agarose gel electrophoresis images showing SSR banding pattern of 10 barley genotypes generated by the primer Bmac0113**

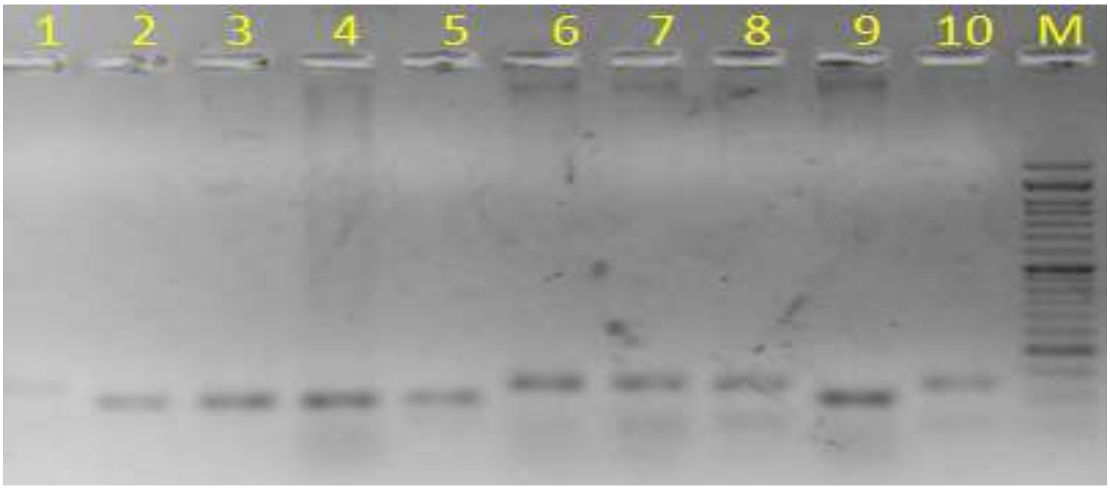

Fig 4.2: **Agarose gel electrophoresis images showing SSR banding pattern of 10 barley genotypes generated by primer Bmag0353**

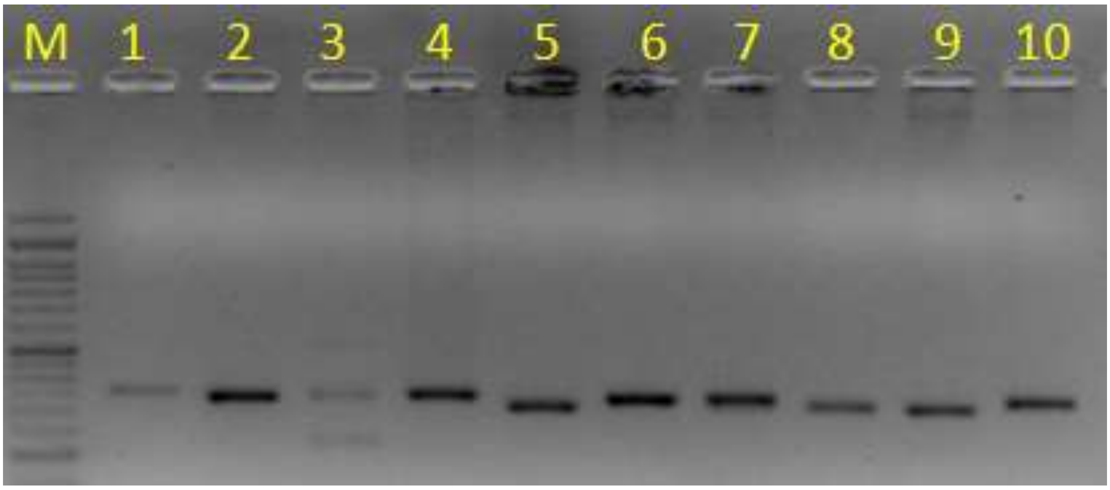

Fig 4.3: **Agarose gel electrophoresis images showing SSR banding pattern of 10 barley genotypes generated by primer EBmac0824**

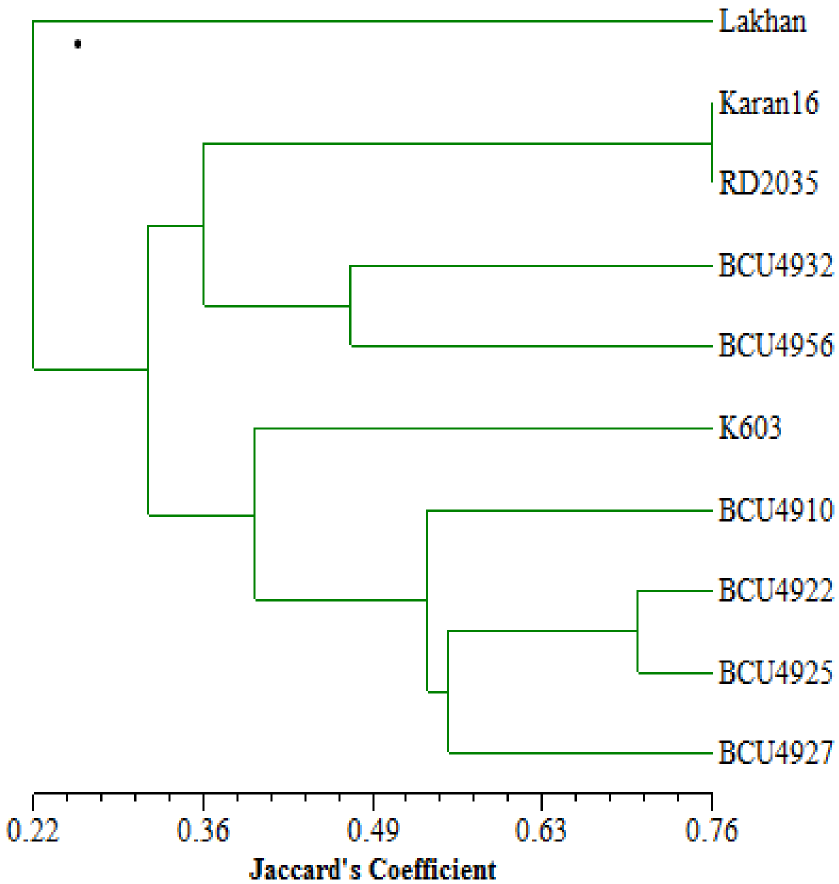

Fig 4.4: **Dendrogram resulting from an UPGMA cluster analysis of 10 barley accessions (Parents') based on data of 14 SSR primer pairs.**

Table 4.1: List of barley SSR markers used for detecting parental polymorphism, the number of allele and the polymorphic information content (PIC).

S.No.	Primer		Sequence 5’-------------- 3’	Length	Chromosome location	No. of alleles	PIC
1.	Bmac0134	F	CCAACTGAGTCGATCTCG	18	2 (2H)	2	0.52
		R	CTTCGTTGCTTCTCTACCTT	20			
2.	Bmag0013	F	AAGGGGAATCAAAATGGGAG	20	3 (3H)	2	0.80
		R	TCGAATAGGTCTCCGAAGAAA	21			
3.	EBmac635	F	TGCTGCGATGATGAGAACT	19	4H	2	0.75
		R	TAGGGTAGATCCGTCCCTATG	21			
4.	Bmag613	F	AAGAACACCATATGATCCAAC	21	6H	2	0.75
		R	CTCCATGACTATGAGGAGAAG	21			
5.	Bmag0125	F	AATTAGCGAGAACAAAATCAC	21	2 (2H)	2	0.74
		R	AGATAACGATGCACCACC	18			
6.	HvABAIP	F	ATGGGAGGGGACAACACCAG	20	1H	2	0.66
		R	GCCCTCGAACGACCAAACAC	20			
7.	HVM36	F	TCCAGCCGAACAATTTCTTG	20	2 (2H)	2	0.66
		R	AGTACTCCGACACCACGTCC	20			
8.	Bmag0378	F	CTTTTGTTTCCGTAGCATCTA	21	2 (2H)	2	0.74
		R	ATCCAACTATAGTAGCAAAGCC	22			
9.	Bmag0223	F	TTAGTCACCCTCAACGGT	18	7 (5H)	2	0.80
		R	CCCCTAACTGCTGTGATG	18			
10.	Bmac0113	F	TCAAAAGCCGGTCTAATGCT	20	7 (5H)	2	0.78
		R	GTGCAAAGAAAATGCACAGATAG	23			
11.	Bmag0353	F	ACTAGTACCCACTATGCACGA	21	4 (4H)	3	0.75
		R	ACGTTCATTAAAATCACAACTG	22			
12.	EBmac0806	F	ACTAAGTCCTTTCACGAGGA	20	6H	2	0.74
		R	GTGTGTAGTAGGTGGGTACTTG	22			
13.	GMS27	F	CTTTTTCTTTGACGATGCACC	21	5H	2	0.78
		R	TGAGTTTGTGAGAACTGGATGG	22			
14.	EBmac0824	F	GCAAGCTTCCTAAATCCTTA	20	5H	2	0.74
		R	TGCAGACAGTTTTTCATATACA	22			
	Total					**29**	**0.73**

Table 4.2: Similarity coefficient among 10 barley genotypes (Parents) based on molecular analysis.

Genotype	Lakhan	Karan16	K603	RD2035	BCU4910	BCU4922	BCU4925	BCU4927	BCU4932	BCU4956
Lakhan	1.00									
Karan16	0.35	1.00								
K603	0.33	0.42	1.00							
RD2035	0.28	0.76	0.35	1.00						
BCU4910	0.05	0.32	0.37	0.45	1.00					
BCU4922	0.21	0.36	0.35	0.36	0.53	1.00				
BCU4925	0.16	0.21	0.37	0.32	0.56	0.71	1.00			
BCU4927	0.21	0.36	0.50	0.36	0.53	0.58	0.53	1.00		
BCU4932	0.16	0.45	0.18	0.45	0.40	0.16	0.17	0.26	1.00	
BCU4956	0.22	0.26	0.08	0.26	0.33	0.45	0.33	0.32	0.47	1.00

Table 4.3.1: Analysis of variance for line x tester analysis of yield and drought related traits of barley under rainfed condition during *rabi* 2011-2012.

Sources of Variations	df	Mean Sum of Squares												
		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Replicates	2	26.77	22.16	1.17	0.02	0.83	1.34	0.03	26.71*	3.96	2.11	6.13	1731.80	0.04
Treatments	33	30.00**	34.54**	133.85**	25.61**	5.28**	11.72**	118.11**	315.12**	306.81**	92.06**	49.48**	14566.33**	0.15*
Parents	9	14.45*	15.47*	108.97**	9.20**	3.31**	2.32	64..94**	178.56**	293.41**	63.80**	49.93**	5056.13*	0.08
Crosses	23	35.42 **	43.43**	140.96**	29.74**	6.25**	10.18**	144.05**	367.51**	324.92**	107.11**	48.10**	17513.51**	0.17**
Parents vs. Crosses	1	135.01**	91.67*	194.06**	78.11**	0.71	131.68**	0.03	339.15**	10.94	0.20	77.07**	32292.05**	0.16*
Lines (Male)	5	4.67	4.76	40.73**	4.76**	3.08**	3.64*	61.36**	187.84**	325.28**	10.01	26.06**	5624.06*	0.09
Testers (Female)	3	5.42	6.33	154.79**	19.67**	3.58**	0.85	66.25**	216.12**	197.72**	159.45**	59.66**	5679.86*	0.07
Lines x Testers	15	19.04	26.93	72.36**	25.62**	6.25**	8.55**	136.32**	211.17**	180.05**	54.46**	37.80**	15620.64**	0.18**
Error	66	17.24	17.52	4.92	1.37	0.47	1.44	5.19	6.10	11.27	5.32	9.17	4214.64	0.08

* Significant at p= 0.05, ** Significant at p= 0.01

Table 4.3.2: Analysis of variance for line x tester analysis of yield and drought related traits of barley under irrigated condition during *rabi* 2012-2013.

Sources of Variations	df	Mean Sum of Squares												
		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Replicates	2	3.31	1.48	26.13	4.09	3.18	10.73	12.21	7.82	0.02	15.17	6.80	1012.19	0.25
Treatments	33	26.89*	25.87*	180.76**	45.92**	2.95**	8.18*	184.89**	164.67**	35.96*	35.95*	44.25**	11649.07*	0.07*
Parents	9	10.25	6.46	109.76*	7.49	3.81**	3.02	491.73**	58.46	40.60*	11.76	39.22	11272.58*	0.06
Crosses	23	14.22	17.12	164.12**	27.90	1.79	3.55	6.57	107.13**	25.85	26.58	45.98**	11098.36*	0.07
Parents vs. Crosses	1	467.95**	401.74**	1202.56**	806.22**	21.94**	161.09**	1524.69**	2443.94**	226.82*	468.97**	49.69	27703.67**	0.21*
Lines (Male)	5	32.92**	36.99**	39.12	13.04	1.67	7.37*	3.32	170.91**	14.52	12.65	104.67**	929.65**	0.07
Testers (Female)	3	19.22	39.07**	692.52**	49.64**	2.29	3.03	5.00	205.73**	25.63	52.66**	21.70	19507.46**	0.07
Lines x Testers	15	6.99	6.11	100.11*	28.51	1.72	2.38	7.97**	66.15*	29.67**	26.01	31.28	12806.11**	0.07
Error	66	16.06	14.30	48.86	23.21	1.38	5.43	16.56	33.81	67.15	29.08	20.29	20103.80	0.11

* Significant at p= 0.05, ** Significant at p= 0.01

Table 4.3.3: Analysis of variance for line x tester analysis of yield and drought related traits of barley under rainfed condition during *rabi* 2012-2013.

Sources of Variations	df	Mean Sum of Squares												
		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Replicates	2	6.07	3.10	218.80*	30.81	4.53	12.16	4.03	85.54	9.32	72.11	34.13	41967.62*	0.25
Treatments	33	60.08**	58.92**	225.35**	41.84*	3.07**	11.05**	270.05**	75.13**	61.62*	46.93**	38.95**	10431.16*	0.20*
Parents	9	9.19	8.11	118.11*	2.57	1.10	2.26	659.99**	43.01	15.31	5.56	11.18	3377.87	0.12
Crosses	23	23.82	20.08	101.17*	30.83	2.80*	9.30*	18.90	73.05*	66.14	39.77	15.30	13247.71**	0.23
Parents vs. Crosses	1	1352.28**	1409.47**	4046.82**	648.68**	26.96**	130.31**	2537.05**	412.00**	374.53**	583.91**	832.88**	9130.00*	0.31
Lines (Male)	5	24.42	11.09	88.42	14.68	4.80	3.45	46.99*	116.28*	26.92	1.89	13.95	6161.95	0.08
Testers (Female)	3	83.89**	87.50**	91.65*	111.73**	4.47	37.65**	13.76	207.18*	90.24**	160.78**	34.32	25793.27*	0.88**
Lines x Testers	15	11.60	9.60	107.32**	20.03	1.81	5.57	10.56	31.81	74.39*	28.19	11.94	13100.52*	0.16
Error	66	27.63	19.00	63.62	21.35	1.51	4.86	17.71	36.88	42.12	23.71	16.95	9541.20	0.23

* Significant at p= 0.05, ** Significant at p= 0.01

Table 4.4.1: Estimates of general combining ability effects for yield and drought related traits in barley under rainfed condition during *rabi* 2011-12.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	2.96**	2.18**	3.62**	1.93**	1.01**	0.82*	0.17	6.66**	1.11	4.25**	1.39	48.25**	-0.60**
BCU 4922	2.46**	2.85**	-2.49**	2.56**	-0.09	1.31**	-3.02**	5.27**	12.78**	5.58**	2.43*	-42.58**	0.21**
BCU 4925	-2.29**	-1.48*	2.55**	-0.43	0.09	-0.26	4.20**	-0.62	3.73**	0.34	-1.07	-10.33	-0.17*
BCU 4927	-2.70**	-3.40**	3.38**	-3.16**	-1.13**	-0.93**	6.56**	-8.75**	-12.37**	-5.08**	-5.37**	10.75	0.03
BCU 4932	2.63**	3.26**	2.04**	0.98*	0.58**	0.32	-3.42**	9.14**	-1.34	1.95*	1.78*	-60.75**	0.10
BCU 4956	-3.04**	-3.40**	-9.10**	-1.39**	-0.46*	-1.26**	-4.49**	-11.70**	-3.92**	-7.04**	0.84	54.67**	-0.80**
Std.Error	±0.79	±0.80	± 0.64	± 0.33	±0.19	±0.34	±0.65	±0.71	± 0.96	±0.66	±0.87	± 18.74	±0.08
Testers													
Lakhan	-0.44**	-0.35*	-5.05**	0.19	0.01	-1.47**	-1.50**	-4.38**	-4.72**	0.26	0.91**	-24.97*	0.01
Karan 16	-0.48**	-0.51**	2.28**	0.90**	0.62**	1.33**	0.03	5.23**	0.34	1.58*	-0.40	-39.08**	0.17*
RD 2035	0.45**	0.57**	2.46**	-0.73*	-0.68**	-0.17	-1.82**	-0.21	1.08	-1.77**	0.26	16.97	-0.14*
K 603	0.38*	-0.40**	0.30	-0.35	0.06	-0.68*	1.29*	-0.63	2.70**	-0.06	-1.12**	-22.91*	0.60**
Std.Error	± 0.19	±0.18	±0.52	±0.27	±0.16	±0.28	±0.53	± 0.58	±0.79	±0.54	±0.25	±11.30	±0.06

***** Significant at P = 0.05, ****** Significant at P= 0.01

Table 4.4.2: Estimates of general combining ability effects for yield and drought related traits in barley under irrigated condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	0.32	-0.14	1.15	-1.51**	-0.14	0.13	-1.77**	0.18	1.78*	-1.88*	-3.65**	7.43	0.07
BCU 4922	0.53	0.19	-0.40	-0.12	-0.74**	-0.74	0.22	-5.20**	0.41	-0.82	-1.17	10.76	-0.20*
BCU 4925	0.18	-0.97	1.40	-0.56	0.17	-0.64	0.10	1.23	-1.70*	-0.65	1.62	-8.24	0.00
BCU 4927	-0.20	1.03	0.77	0.29	-0.07	0.85	-0.24	-0.24	0.13	1.91*	-1.11	-41.15*	0.35**
BCU 4932	2.13**	2.53*	0.54	0.27	0.66**	1.01*	-0.13	-2.14	-0.18	1.81*	-0.66	4.01	0.06
BCU 4956	-2.95**	-2.64*	-3.46**	1.63**	-0.39	-0.60	0.81	6.16**	-0.65	0.32	4.97**	-2.82	-0.09
Std.Error	±0.95	±1.09	± 1.01	± 0.39	±0.23	±0.47	±0.37	±1.67	± 0.86	±0.85	±1.01	± 20.00	±0.09
Testers													
Lakhan	1.93**	1.22	7.43**	1.57**	0.00	0.97**	-0.05	3.29*	0.57	1.98**	-1.22	-9.51	0.09
Karan 16	-0.43	-0.89	-3.46**	-0.91*	-0.23	-0.15	0.73*	-1.58	1.27	-0.62	0.52	39.71**	-0.01
RD 2035	-1.82**	-1.61**	-6.48**	-1.87**	-0.28	-0.40	-0.51	-3.98**	-1.49*	-2.01**	-0.55	8.65	-0.13**
K 603	0.51	1.28	2.51	1.22**	0.50*	-0.02	-0.16	2.28	-0.36	0.65	1.25	-38.85**	-0.05
Std.Error	± 0.84	±0.69	±1.64	±0.33	±0.21	±0.34	±0.35	± 1.37	±0.73	±0.79	±0.96	±13.41	±0.07

***** Significant at P = 0.05, ****** Significant at P= 0.01

Table 4.4.3: Estimates of general combining ability effects for yield and drought related traits in barley under rainfed condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	-0.69	1.21*	1.60	1.14	0.15	-0.14	2.36**	0.53	-2.08**	-0.14	-1.04	8.60	-0.01
BCU 4922	1.14	0.54	1.24	0.89	0.85*	-0.30	0.79	-4.24*	-1.34	0.06	0.83	-14.57	-0.10**
BCU 4925	2.64**	1.21*	2.85**	-0.62	0.02	-0.79**	0.67	-1.60	0.27	0.30	1.97*	21.26	0.09**
BCU 4927	0.81	0.71	1.92	0.04	-0.27	0.77**	-0.31	0.52	1.32	2.44**	-0.73	28.76	-0.05
BCU 4932	-2.41**	-0.88	-4.31**	-1.87**	0.30	0.13	1.34	-0.43	0.02	0.03	-0.48	-25.99	0.10**
BCU 4956	-0.78	-0.38	-2.50	0.42	-1.05**	0.32	-3.84**	5.22**	1.81*	-0.69	-0.35	-18.07	-0.03
Std.Error	±1.11	±0.51	± 1.30	± 0.63	±0.35	±0.23	±0.81	±1.75	± 0.87	±1.01	±0.94	± 18.29	±0.03
Testers													
Lakhan	0.94	1.04*	1.45	2.35**	-0.19	1.75**	-0.79	2.41	0.02	2.09*	-1.95*	-44.90**	0.27**
Karan 16	-2.89**	-2.79**	-2.56**	-1.09	0.73*	-1.02**	0.69	-1.44	-2.36**	-2.02*	0.41	28.88*	-0.26**
RD 2035	-0.22	-0.57	-1.18	-2.99**	-0.39	-1.34**	0.82	-4.10**	-0.67	-3.06**	0.23	33.71**	-0.05
K 603	2.17*	2.32**	2.29**	1.03	-0.16	0.62*	-0.72	3.13*	3.01**	2.99**	1.31	-17.68	0.04
Std.Error	± 1.03	±0.42	±1.08	±0.58	±0.28	±0.21	±0.79	± 1.43	±0.52	±0.97	±0.91	±13.02	±0.09

***** Significant at P = 0.05, ****** Significant at P= 0.01

Table 4.5.1: Estimates of specific combining ability effects for yield and drought related traits in barley under rainfed condition during *rabi* 2011-12.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	1.71	-0.46	1.80	2.57**	0.13	0.44	-1.29	0.46	4.89*	6.73**	-1.62	-3.36	0.02
BCU 4910 x Karan 16	0.49	-0.51	-0.53	1.06	0.24	1.01	4.31**	-2.21	-2.26	-0.25	1.19	-12.58	-0.17
BCU 4910 x RD 2035	-3.01	-2.74	-4.46**	-1.31	-1.14**	-1.57*	-4.71**	-3.80*	-3.71	-7.14**	1.76	1.36	-0.03
BCU 4910 x K 603	0.82	3.71*	3.19*	-2.28**	0.78	0.13	1.69	5.55**	1.08	0.66	-1.33	14.58	0.18
BCU 4922 x Lakhan	0.88	2.21	0.38	1.38*	0.14	0.20	3.79**	0.49	1.46	2.35	-0.06	-19.19	0.16
BCU 4922 x Karan 16	-1.68	-2.18	2.10	-1.86**	0.82*	-0.28	-2.37	-1.76	3.06	-3.44*	4.42*	71.58	-0.33*
BCU 4922 x RD 2035	-1.85	-2.40	-4.87**	-1.13	-0.78	-1.73*	-0.65	-10.23**	-1.72	-4.78**	-7.23**	15.53	0.28
BCU 4922 x K 603	2.65	2.38	2.40	1.61*	-0.18	1.81*	-0.77	11.51**	-2.80	5.88**	2.87	-67.92	-0.11
BCU 4925 x Lakhan	-2.38	-3.79*	0.64	-4.62**	-1.91**	-1.76*	7.76**	-3.19*	-5.72**	-2.31	4.31*	58.56	0.13
BCU 4925 x Karan 16	3.07*	2.49	-0.66	4.03**	0.90*	2.06**	-4.74**	8.32**	10.35**	0.30	-1.41	-37.33	0.28
BCU 4925 x RD 2035	2.90	4.93**	3.21*	4.03**	2.37**	1.57*	-5.05**	11.42**	8.71**	4.82**	-0.11	-17.72	-0.02
BCU 4925 x K 603	-3.60*	-3.63*	-3.18*	-3.44**	-1.36**	-1.88*	2.04	-16.55**	-13.34**	-2.80*	-2.79	-3.50	-0.38*
BCU 4927 x Lakhan	0.38	1.46	-9.38**	1.40*	1.34**	1.05	-13.51**	4.15**	4.14*	-3.20*	1.34	54.14	-0.14
BCU 4927 x Karan 16	-3.85*	-2.60	4.26**	-2.54**	-1.03*	-1.86*	2.33	-5.73**	3.09	0.45	-2.34	-5.08	0.29
BCU 4927 x RD 2035	0.65	-1.15	9.73**	-0.24	0.82*	1.35	15.61**	-5.39**	-2.56	2.71*	-1.51	-71.14	-0.04
BCU 4927 x K 603	2.82	2.29	-4.61**	1.37*	-1.10**	-0.54	-4.42**	6.97**	-4.67*	0.05	2.51	22.08	-0.11
BCU 4932 x Lakhan	0.04	-0.21	3.62**	1.19	0.26	-1.14	2.65*	-5.38**	2.49	-3.02*	-4.43*	-21.03	-0.14
BCU 4932 x Karan 16	1.15	1.40	-3.02*	-3.09**	-1.62**	-0.35	-2.44	2.02	-10.80**	0.43	0.47	-46.25	0.15
BCU 4932 x RD 2035	0.99	1.51	-0.52	-0.62	0.94*	-0.70	-0.02	2.50	-1.45	1.93	4.94*	-59.64	-0.07
BCU 4932 x K 603	-2.18	-2.71	-0.08	2.52**	0.41	2.18**	-0.19	0.86	9.76**	0.68	-0.98	126.91**	0.06
BCU 4956 x Lakhan	-0.63	0.79	2.94*	-1.92**	0.04	1.22	0.60	3.47*	-7.26**	-0.53	0.46	-69.11	-0.03
BCU 4956 x Karan 16	0.82	1.40	-2.15	2.42**	0.70	-0.59	2.92*	-0.64	-3.43	2.53	-2.33	29.67	-0.22
BCU 4956 x RD 2035	0.32	-0.15	-3.07*	-0.71	-2.20**	1.09	-5.17**	5.51**	0.73	2.47	2.14	131.61**	-0.12
BCU 4956 x K 603	-0.51	-2.04	2.29	0.21	1.46**	-1.70*	1.66	-8.34**	9.97**	-4.46**	-0.28	-92.16*	0.37*
Std. Error	±1.52	± 1.41	± 1.40	± 0.67	± 0.39	± 0.69	± 1.31	± 1.42	± 1.93	± 1.33	± 1.74	± 37.48	± 0.16

***** Significant at p= 0.05, ****** Significant at p= 0.01

Table 4.5.2: Estimates of specific combining ability effects for yield and drought related traits in barley under rainfed condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	-0.53	-0.63	3.60**	0.77	0.58	-1.15	3.01**	-0.94	-2.60	0.18	-0.68	-0.10	0.02
BCU 4910 x Karan 16	0.97	0.88	-1.06	-0.86	-0.89	1.30	-2.28*	5.01**	-1.52	-1.16	-1.87	-100.54**	0.16
BCU 4910 x RD 2035	0.31	0.32	-3.57**	-0.16	0.05	-0.43	-0.40	-1.33	2.77	0.04	2.35*	41.29	-0.12
BCU 4910 x K 603	-0.75	-0.57	1.03	0.25	0.27	0.28	-0.33	-2.73	1.35	0.94	0.20	59.35	-0.06
BCU 4922 x Lakhan	2.97*	2.96**	1.43	4.27**	-0.31	2.86**	-0.89	0.89	6.41**	4.79**	0.51	-60.26	-0.05
BCU 4922 x Karan 16	-0.86	-1.54	2.44	-0.35	0.56	0.24	-0.64	-0.19	-2.06	-1.37	1.02	79.29	0.12
BCU 4922 x RD 2035	-1.53	-0.76	1.26	-1.74	0.08	-1.55	-1.03	0.83	-0.45	-1.25	0.11	-5.54	-0.15
BCU 4922 x K 603	-0.58	-0.65	-5.14**	-2.18	-0.33	-0.54	2.57*	-1.53	-3.90*	-2.18	-2.64*	-13.49	0.08
BCU 4925 x Lakhan	-2.19	-2.38*	-2.19	-0.06	0.25	0.62	1.89	-1.34	-4.88**	-0.47	0.67	-88.76*	0.36
BCU 4925 x Karan 16	0.31	0.46	3.29**	-1.76	1.59**	-2.64*	1.47	-3.23*	-1.34	-1.26	1.75	26.79	-0.11
BCU 4925 x RD 2035	0.64	0.90	-0.55	-0.81	-1.12*	0.81	-1.12	1.60	0.80	-0.75	-2.87**	21.96	-0.04
BCU 4925 x K 603	1.25	1.01	-0.55	2.63*	-0.72	0.20	-2.25*	2.97	5.42**	2.48	0.45	40.01	-0.21
BCU 4927 x Lakhan	-1.69	-0.54	3.01*	-4.65**	0.29	-1.09	-0.46	-3.63*	-3.80	-5.64**	0.17	89.74*	-0.35
BCU 4927 x Karan 16	0.14	-0.04	-1.51	0.98	-0.74	1.10	0.46	1.96	3.67	2.17	-2.35*	25.96	-0.10
BCU 4927 x RD 2035	-0.53	-0.93	0.58	4.69**	0.86	0.59	1.27	0.72	-5.25**	4.55**	1.70	-41.54	0.48*
BCU 4927 x K 603	2.08	1.51	-2.09	-1.02	-0.41	-0.60	-1.27	0.95	5.38**	-1.08	0.48	-74.15	-0.04
BCU 4932 x Lakhan	1.56	1.71	-2.95*	1.67	-0.17	1.52	-2.24*	6.08**	2.61	3.31**	-0.67	-33.85	0.15
BCU 4932 x Karan 16	-0.94	-0.79	-12.67**	-0.67	-0.23	-1.96	-0.19	-2.07	-4.09*	-1.65	-0.99	-0.96	0.02
BCU 4932 x RD 2035	-1.94	-2.01	4.28**	-1.16	-0.20	0.68	2.02	-4.84**	0.25	-2.96	-1.48	12.54	-0.25
BCU 4932 x K 603	1.33	1.10	11.35**	0.16	0.60	-0.23	0.42	0.83	1.24	1.49	3.14**	22.26	0.08
BCU 4956 x Lakhan	-0.11	-1.13	-2.90*	-2.00	-0.63	-1.76	-1.32	-1.06	2.27	-1.97	0.00	93.24**	-0.12
BCU 4956 x Karan 16	0.39	1.04	9.51**	2.65*	-0.28	0.96	1.19	-1.48	5.34**	3.26*	1.44	-30.54	-0.09
BCU 4956 x RD 2035	3.06**	2.49*	-2.00	-0.83	0.32	-0.10	-0.73	3.02*	1.88	0.37	0.19	-28.71	0.07
BCU 4956 x K 603	-3.33**	-2.40*	-4.60**	0.17	0.59	0.90	0.87	-0.48	-9.49**	-1.67	-1.63	-33.99	0.15
Std. Error	±1.43	± 1.11	± 1.40	± 1.26	± 0.50	± 1.27	± 1.02	± 1.49	± 1.94	± 1.61	± 0.97	± 41.39	± 0.21

***** Significant at p= 0.05, ****** Significant at p= 0.01

Table 4.5.3: Estimates of specific combining ability effects for yield and drought related traits in barley under irrigated condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/ m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	-1.49	-1.31	-9.57**	-4.49**	0.05	-1.55*	1.60	-7.89**	-2.74	-4.84**	4.13**	-62.49	0.19
BCU 4910 x Karan 16	-0.93	-0.53	2.85	-0.22	0.50	0.91	-2.04*	3.40	0.08	-1.05	-1.24	48.63	-0.05
BCU 4910 x RD 2035	0.62	0.53	4.94**	3.20**	0.07	0.30	-0.77	3.67	-0.68	4.80**	-2.93	-19.32	0.09
BCU 4910 x K 603	1.80	1.31	1.78	1.51	-0.62	0.34	1.21	0.82	3.35	1.09	0.05	33.18	-0.33*
BCU 4922 x Lakhan	-0.03	-0.31	12.09**	2.38*	-0.22	0.50	0.11	5.15**	-0.10	0.74	0.09	84.18	-0.22
BCU 4922 x Karan 16	1.86	-0.19	1.89	3.54**	0.61	-0.22	-1.00	4.39*	3.30	2.14	1.32	27.96	0.09
BCU 4922 x RD 2035	-1.35	-0.14	-7.38**	-1.97	-0.77	0.08	2.17*	-2.20	1.97	-0.20	-1.80	-98.99**	0.16
BCU 4922 x K 603	-0.47	0.64	-6.60**	-3.95**	0.38	-0.36	-1.28	-7.34**	-5.17**	-2.68	0.39	-13.15	-0.03
BCU 4925 x Lakhan	0.02	1.19	-0.19	0.07	0.58	0.90	-1.56	3.06	1.90	1.61	-3.43*	-10.15	-0.18
BCU 4925 x Karan 16	0.21	0.31	-2.67	-1.86	-0.42	-0.28	1.22	-4.52**	-3.42	-3.71**	3.33*	-37.38	0.14
BCU 4925 x RD 2035	1.17	-0.31	2.59	1.67	0.99	-0.62	1.96	-0.16	0.43	-1.41	3.14*	15.01	-0.04
BCU 4925 x K 603	-1.39	-1.19	0.26	0.12	-1.15*	0.00	-1.62	1.61	1.09	3.51**	-3.03*	32.51	0.08
BCU 4927 x Lakhan	-0.63	-2.14*	1.71	-0.96	-0.20	0.01	0.60	-2.55	-2.56	-0.77	-0.38	43.76	0.11
BCU 4927 x Karan 16	-1.74	-1.03	-2.33	1.35	0.13	0.23	1.25	-0.38	1.48	0.78	-1.25	89.79*	-0.02
BCU 4927 x RD 2035	0.38	1.36	-0.48	1.72	-0.55	-0.38	-2.87**	2.96	0.67	0.07	1.16	117.60**	-0.15
BCU 4927 x K 603	1.99*	1.81	1.10	-2.11*	0.62	0.13	1.01	-0.03	0.40	-0.07	0.46	-71.57	0.06
BCU 4932 x Lakhan	0.70	1.03	0.78	3.20**	0.14	-0.18	-0.04	1.02	1.36	3.70**	-2.69	-8.40	0.01
BCU 4932 x Karan 16	-1.07	-0.19	-5.42**	-4.29**	-1.22*	-0.92	0.07	-4.90**	1.89	-1.30	-3.13*	2.04	-0.13
BCU 4932 x RD 2035	0.38	-0.47	2.35	-0.87	-0.20	-0.34	-0.81	-2.92	0.56	-2.61	5.35**	16.10	0.05
BCU 4932 x K 603	-0.01	-0.36	2.29	1.97	1.18*	1.44*	0.77	6.79**	-3.81	0.21	0.48	-9.74	0.07
BCU 4956 x Lakhan	1.45	1.53	-4.82**	-0.19	-0.35	0.32	-0.71	1.20	2.14	-0.44	2.28	-46.90	0.09
BCU 4956 x Karan 16	1.68	1.64	5.69**	1.48	0.30	0.28	0.50	2.00	-3.33	3.16*	0.98	48.54	-0.03
BCU 4956 x RD 2035	-1.20	-0.97	-2.02	-3.75**	0.46	0.95	0.31	-1.35	-2.95	-0.66	-4.91**	-30.40	-0.11
BCU 4956 x K 603	-1.92*	-2.19*	1.16	2.47*	-0.41	-1.55*	-0.10	-1.85	4.14*	-2.06	1.65	28.76	0.06
Std. Error	± 0.91	± 0.98	± 2.03	± 1.18	± 0.57	± 0.64	± 0.94	± 2.05	± 2.00	± 1.51	± 1.49	± 42.86	± 0.15

***** Significant at p= 0.05, ****** Significant at p= 0.01

Table 4.6.1: Estimates of genetic components of variance (σ^2A and σ^2D) and degree of dominance for yield and drought related traits of barley under rainfed conditions during *rabi* 2011-2012.

Components of variance	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
σ^2 Male	7.26	8.31	24.46	4.42	0.53	0.89	19.92	73.46	68.83	25.28	7.58	1857.33	0.05
σ^2 Female	-0.82	-0.81	12.02	0.43	0.25	0.75	0.58	15.34	10.22	1.61	0.20	432.30	0.05
σ^2 GCA	2.41	2.83	17.00	2.02	0.37	0.81	8.31	38.59	33.66	11.08	3.15	1002.31	0.05
σ^2 SCA	0.59	3.13	22.48	8.08	1.92	2.37	43.71	68.35	56.26	16.38	9.54	3801.99	0.03
σ^2 A	4.82	5.67	34.00	4.05	0.74	1.62	16.63	77.18	67.33	22.16	6.31	2004.62	0.09
σ^2 D	0.59	3.13	22.48	8.08	1.92	2.37	43.71	68.35	56.26	16.38	9.54	3801.99	0.03
Degree of Dominance $\sqrt{(\sigma 2\ D / \sigma 2\ A)}$	0.35	0.74	0.81	1.41	1.61	1.21	1.62	0.94	0.91	0.86	1.23	1.37	1.87

Table 4.6.2: Estimates of genetic components of variance (σ^2A and σ^2D) and degree of dominance for yield and drought related traits of barley under rainfed conditions during *rabi* 2012-2013.

Components of variance	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
σ^2 Male	3.27	-0.66	2.07	-0.56	0.27	-0.12	2.44	6.62	-1.27	-1.82	-0.25	-281.60	-0.01
σ^2 Female	3.13	3.81	1.56	5.02	0.16	1.82	-0.22	9.46	2.67	7.62	0.97	902.89	0.04
σ^2 GCA	1.77	2.02	1.76	2.79	0.21	1.05	0.84	8.32	1.10	3.84	0.48	429.09	0.02
σ^2 SCA	-5.34	-3.13	14.57	-0.44	0.10	0.24	-2.38	-1.69	10.76	1.49	-1.67	1186.44	-0.02
σ^2 A	3.54	4.04	3.52	5.58	0.42	2.09	1.69	16.65	2.20	7.68	0.96	858.19	0.03
σ^2 D	-5.34	-3.13	14.57	-0.44	0.10	0.24	-2.38	-1.69	10.76	1.49	-1.67	1186.44	-0.02
Degree of Dominance $\sqrt{(\sigma 2 D / \sigma 2 A)}$	1.23	0.88	2.03	0.28	0.49	0.34	1.19	0.32	2.21	0.44	1.32	1.18	0.87

Table 4.6.3: Estimates of genetic components of variance (σ^2A and σ^2D) and degree of dominance for yield and drought related traits of barley under irrigated conditions during *rabi* 2012-2013.

Components of variance	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest Index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
σ^2 Male	1.41	1.89	-0.81	-0.85	0.02	0.16	-1.10	11.42	-4.39	-1.37	7.03	-1597.85	0.01
σ^2 Female	0.18	1.38	35.76	1.47	0.05	-0.13	-0.64	9.55	-2.31	1.31	0.08	-33.13	0.02
σ^2 GCA	0.67	1.58	21.13	0.54	0.04	-0.02	-0.83	10.30	-3.14	0.24	2.86	-659.02	0.04
σ^2 SCA	-3.02	-2.73	17.08	1.77	0.12	-1.02	-2.86	10.78	-12.49	-1.02	3.66	-2432.56	-0.01
σ^2 A	1.34	3.16	42.26	1.08	0.08	-0.03	-1.65	20.60	-6.28	0.48	5.72	-1318.03	-0.02
σ^2 D	-3.02	-2.73	17.08	1.77	0.12	-1.02	-2.86	10.78	-12.49	-1.02	3.66	-2432.56	-0.01
Degree of Dominance $\sqrt{(\sigma 2 D / \sigma 2 A)}$	1.50	0.93	0.64	1.28	1.20	5.73	1.32	0.72	1.41	1.46	0.80	1.36	1.61

Table 4.7: Proportional contribution of line, tester and their interactions to total variance in barley.

S.No.	Traits	Rainfed 2011-2012			Irrigated 2012-2013			Rainfed 2012-2013		
		Line (%)	Tester (%)	Line x Tester (%)	Line (%)	Tester (%)	Line x Tester (%)	Line (%)	Tester (%)	Line x Tester (%)
1	Days to 50 % flowering	64.09	0.86	35.04	50.31	17.62	32.06	22.29	45.94	31.76
2	Days to maturity	58.72	0.85	40.43	46.97	29.77	23.26	12.01	56.83	31.16
3	Plant height(cm)	46.04	20.48	33.48	5.18	55.04	39.78	19.00	11.82	69.18
4	Number of effective tillers	39.82	3.99	56.19	10.16	23.21	66.64	10.35	47.28	42.37
5	spike length (cm)	24.09	10.70	65.21	20.34	16.73	62.93	37.19	20.77	42.04
6	Awn length(cm)	25.95	19.25	54.80	45.15	11.13	43.72	8.07	52.82	39.11
7	Number of grains per spike	36.86	1.42	61.72	10.97	9.92	79.11	54.05	9.50	36.45
8	Thousand grain weight (g)	52.51	10.02	37.47	34.68	25.05	40.27	34.61	36.99	28.40
9	Harvest index	56.02	7.84	36.14	12.21	12.93	74.86	8.85	17.80	73.35
10	Grain yield per plant (g)	62.65	4.19	33.16	10.34	25.84	63.82	1.04	52.73	46.23
11	Chlorophyll content	45.26	3.49	51.25	49.48	6.15	44.36	19.82	29.27	50.91
12	Stomatal conductance (m mol/m^2/s)	32.90	8.93	58.17	1.82	22.93	75.25	10.11	25.40	64.49
13	Proline content (mg/g)	17.45	12.97	69.58	21.17	13.86	64.97	7.30	48.92	43.78

Table 4.8.1: General mean, heritability (narrow sense), genetic advance and genetic advance as per cent of mean for yield and drought related traits of barley under rainfed condition during *rabi* 2011-2012.

Traits	General mean	Heritability (Narrow Sense) %	Genetic Advance 5 %	GA as % of mean
Days to 50% flowering	81.78	43.17	2.97	3.63
Days to maturity	114.26	38.72	3.05	2.67
Plant height (cm)	71.73	58.50	9.18	12.80
Number of effective tillers	15.30	32.19	2.35	15.38
Spike length (cm)	8.70	26.23	0.90	10.44
Awn length (cm)	14.92	36.22	1.57	10.57
Number of grains per spike	26.86	26.80	4.35	16.19
Thousand grain weight (g)	54.71	52.30	13.08	23.92
Harvest index	70.78	52.87	12.29	17.36
Grain yield per plant (g)	17.51	54.97	7.19	41.06
Chlorophyll content	47.31	33.37	2.98	6.31
Stomatal conductance (m mol/m^2/s)	1284.90	27.79	48.62	3.78
Proline content (mg/g)	2.53	13.54	0.07	29.24

Table 4.8.2: General mean, heritability (narrow sense), genetic advance and genetic advance as per cent of mean for yield and drought related traits of barley under rainfed condition during *rabi* 2012-2013.

Traits	General mean	Heritability (Narrow Sense) %	Genetic Advance 5 %	GA as % of mean
Days to 50% flowering	81.26	47.78	2.68	3.30
Days to maturity	114.72	55.81	3.09	2.70
Plant height (cm)	67.48	8.96	1.16	1.72
Number of effective tillers	11.43	45.54	3.28	28.73
Spike length (cm)	8.06	40.86	0.85	10.54
Awn length (cm)	14.88	52.96	2.17	14.57
Number of grains per spike	25.71	32.42	1.52	5.93
Thousand grain weight (g)	54.63	61.09	6.57	12.02
Harvest index	56.19	8.13	0.87	1.55
Grain yield per plant (g)	11.09	44.98	3.83	34.53
Chlorophyll content	41.22	19.41	0.89	2.16
Stomatal conductance (m mol/m^2/s)	1279.17	16.42	24.46	1.91
Proline content (mg/g)	2.52	38.54	0.23	9.19

Table 4.8.3: General mean, heritability (narrow sense), genetic advance and genetic advance as per cent of mean for yield and drought related traits of barley under irrigated condition during *rabi* 2012-2013.

Traits	General mean	Heritability (Narrow Sense) %	Genetic Advance 5 %	GA as % of mean
Days to 50% flowering	81.32	36.42	1.44	1.77
Days to maturity	113.60	60.85	2.86	2.52
Plant height (cm)	85.24	55.88	10.01	11.74
Number of effective tillers	13.71	10.23	0.69	5.00
Spike length (cm)	8.70	12.28	0.20	2.35
Awn length (cm)	15.26	4.07	0.07	1.48
Number of grains per spike	28.61	64.55	3.40	11.88
Thousand grain weight (g)	53.60	48.30	6.50	12.12
Harvest index	59.02	73.68	6.80	11.52
Grain yield per plant (g)	15.13	5.22	0.32	2.15
Chlorophyll content	43.34	35.42	2.93	6.77
Stomatal conductance (m mol/m^2/s)	1463.93	44.67	49.98	3.41
Proline content (mg/g)	1.46	31.98	0.09	5.85

Table 4.9.1: Estimates of standard heterosis and better parent heterosis for yield and drought related traits of barley under rainfed condition during *rabi* 2011-12.

Crosses \ Traits	Days to 50% flowering		Days to maturity		Plant height (cm)		Number of effective tillers		Spike length (cm)		Awn length (cm)		Number of grains per spike	
	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
BCU 4910 x Lakhan	13.22**	1.58	5.49	-0.29	-5.88*	-18.38**	45.05**	2.12	26.72**	-4.85	25.56**	-14.05*	-50.78**	-27.29**
BCU 4910 x Karan 16	11.01*	-1.18	5.18	-1.99	0.74	3.95	39.05**	18.18**	36.08**	36.08**	45.53**	16.98*	-38.84**	28.87**
BCU 4910 x RD 2035	7.49	-3.56	3.96	-1.73	-4.24	-5.28*	8.93	-11.36	1.29	-16.07*	11.17	-19.92**	-58.10**	-29.19**
BCU 4910 x K 603	12.33**	0.79	9.15**	3.17	3.04	0.29	4.73	-22.04**	35.78**	8.62	21.23*	-14.23*	-41.49**	16.22*
BCU 4922 x Lakhan	11.45*	0.4	-8.54**	2.3	-15.85**	-27.02**	40.80**	-0.88	12.5	-15.53*	27.65**	-12.62*	-47.10**	-21.85**
BCU 4922 x Karan 16	7.49	-4.31	4.27	-2.84	-3.87	1.49	21.89**	-10.26	29.31**	-0.33	38.83**	2.47	-58.08**	-19.69**
BCU 4922 x RD 2035	8.37	-1.6	4.88	-1.15	-12.86**	-13.81**	15.17*	-15.20**	-8.19	-29.24**	13.97	-17.91**	-56.39**	-26.31**
BCU 4922 x K 603	14.10**	3.6	8.54**	2.3	-6.10*	-8.61**	38.56**	2.01	9.05	-15.95*	39.39**	-1.38	-52.50**	-8.99
BCU 4925 x Lakhan	0.88	-9.13*	-0.91	-7.41*	-8.83 **	-20.94**	-26.37**	-48.16**	-11.64	-33.66**	-1.96	-33.65**	-25.29**	10.37
BCU 4925 x Karan 16	7.49	-4.31	4.57	-2.56	-0.85	1.39	43.53**	23.29**	32.76**	21.74**	45.25**	-1.7	-48.63**	-3.55
BCU 4925 x RD 2035	8.37	-1.99	7.62*	0.57	4.5	3.36	31.34**	6.88	34.91**	11.79	28.49**	-13.04*	-50.89**	-17.01**
BCU 4925 x K 603	-0.44	-9.96*	-0.91	-7.41*	-6.81**	-9.29**	-21.64**	-41.67**	-3.88	-23.10**	-4.75	-35.54**	-32.93**	25.91**
BCU 4927 x Lakhan	3.96	-8.17*	2.13	-5.1	-20.97**	-31.46**	-1.74	-30.82**	14.66*	-13.92*	15.92	-23.57**	-62.16**	-44.09**
BCU 4927 x Karan 16	-2.2	-13.62**	-1.83	-8.78**	6.77**	15.71**	-25.87**	-43.02**	-8.19	-17.12*	6.7	-29.65**	-30.25**	26.33**
BCU 4927 x RD 2035	4.85	-7.39	0.3	-6.80*	14.22**	12.97 **	-20.90**	-39.20**	-1.29	-18.21**	20.95*	-20.26**	-6.03	58.79**
BCU 4927 x K 603	7.49	-5.06	2.74	-4.53	-7.60**	-10.06**	-5.97	-30.00**	-16.38*	-33.10**	0.84	-33.52**	-40.94**	6.98
BCU 4932 x Lakhan	10.57*	-0.4	6.71*	1.74	-5.56*	-18.10**	23.88**	-12.78*	22.89**	-7.73	8.1	-26.00**	-50.10**	-26.28**
BCU 4932 x Karan 16	11.45*	-0.78	7.93*	0.57	-4.65	-3.27	-2.74	-14.44*	6.47	1.23	29.89**	-4.12	-59.00**	-18.45*
BCU 4932 x RD 2035	12.33**	2.82	8.84**	4.08	-1.11	-2.18	3.48	-15.79**	22.84**	1.79	14.25	-17.71**	-55.94**	-25.54**
BCU 4932 x K 603	7.93	-0.41	4.27	-0.29	-3.38	-5.96*	29.85**	-3.33	25.43**	0.34	34.22**	-5.04	-52.14**	-4.94
BCU 4956 x Lakhan	2.2	-7.94	1.52	-4.58	-21.19**	-31.65**	-13.43	-39.05**	6.47	-20.06**	14.53	-21.61**	-56.20**	-35.29**
BCU 4956 x Karan 16	3.52	-7.84	1.83	-5.11	-18.22**	-11.37**	24.38**	-5.66	22.84**	4.01	14.53	-19.13**	-50.63**	-10.58
BCU 4956 x RD 2035	3.96	-5.22	1.22	-4.87	-19.22**	-20.10**	-11.19	-32.64**	-31.47**	-43.21**	15.92	-18.15**	-68.08**	-46.06**
BCU 4956 x K 603	2.64	-6.43	-1.22	-7.16*	-14.98**	-17.25**	-1.49	-26.67**	25.43**	0.34	-11.73	-37.67**	-50.63**	-10.59

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Crosses \ Traits	Thousand grain weight (g)		Harvest Index		Grain yield per plant (g)		Chlorophyll content		Stomatal conductance (m mol/m^2/s)		Proline content (mg/g)	
	SH	BPH	SH	BH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
BCU 4910 x Lakhan	70.21**	-21.50**	34.58**	-17.39**	95.80**	-3.18	12.58*	-12.11*	4.23	2.07	17.91	-4.66
BCU 4910 x Karan 16	86.11**	-11.83**	30.65**	-19.81**	79.52**	25.39*	17.01**	-8.65	3.17	1.83	11.68	-9.69
BCU 4910 x RD 2035	90.82**	-21.64**	30.46**	-19.92**	27.53	-30.33**	19.07**	-7.04	7.94	-0.73	8.65	-12.15*
BCU 4910 x K 603	89.18**	-9.19**	41.32**	-13.26**	82.22**	21.40*	8.47	-15.32**	4.23	-1.62	27.16*	2.82
BCU 4922 x Lakhan	86.08**	-14.15**	50.00**	6.42	85.39**	-13.48*	18.75**	-4.64	-4.23	-6.31	29.74**	9.2
BCU 4922 x Karan 16	82.59**	7.47*	62.48**	15.28**	81.01**	11.61	27.14**	2.1	2.65	0.41	10.32	-5.22
BCU 4922 x RD 2035	80.57**	-17.40**	56.05**	10.72**	64.18**	-13.16	0.16	-19.57**	1.85	-6.33	28.22*	10.17*
BCU 4922 x K 603	92.24**	17.38**	55.93**	10.63**	97.40**	52.02**	20.89**	-2.92	-9.52*	-14.61**	19.58	-3.19
BCU 4925 x Lakhan	69.30**	-29.13**	19.60**	-2.39	56.88**	-46.85**	20.81**	5.67	4.5	-0.75	15.93	-2.43
BCU 4925 x Karan 16	91.25**	23.86**	59.18**	14.35**	76.02**	27.10*	4.98	-7.33	-3.44	-8.29*	25.34*	11.62*
BCU 4925 x RD 2035	69.46**	9.54**	58.62**	29.45**	77.63**	26.21*	8.78	-8.94	1.77	-6.4	2.12	-5.21
BCU 4925 x K 603	33.39**	-39.84**	19.23**	-12.83**	48.76*	-13.17	-0.87	-12.50*	-1.85	-7.37	-5.61	-23.59**
BCU 4927 x Lakhan	66.41**	-30.34**	7.93	-5.21	-5.94	-68.13**	3.56	-10.77*	5.82	1.78	12.14	-5.62
BCU 4927 x Karan 16	65.38**	-15.65**	15.42**	-17.09**	43.58*	-9.81	-7.44	-20.25**	0.79	-3.05	34.29**	19.59*
BCU 4927 x RD-2035	46.27**	-33.09**	7.37	-2.49	32.67	-19.35*	-4.75	-20.26**	-0.79	-8.76*	9.71	1.83
BCU 4927 x K 603	60.90**	-13.90**	5.31	-23.00**	23.22	-28.07*	1.5	-12.54*	1.85	-3.87	15.33	-6.63
BCU 4932 x Lakhan	77.61**	-17.28**	25.47**	-16.39**	65.84**	-43.82**	6.8	-14.45**	-5.82	-12.32**	15.33	-2.94
BCU 4932 x Karan 16	96.19**	11.52**	10.05	-26.66**	73.43**	51.77**	16.22 **	-6.91	-8.15*	-14.48**	31.41**	17.03*
BCU 4932 x RD 2035	82.59**	3.58	30.09**	-13.31**	84.89**	18.47*	27.53**	2.15	-5.56	-13.14**	11.84	2.5
BCU 4932 x K 603	84.92**	0.3	53.00**	1.96	89.50**	16.46*	10.21	-11.72*	4.5	-2.71	26.71*	2.58
BCU 4956 x Lakhan	52.82**	-36.03**	2.37	-31.24**	1.16	-65.73**	16.22**	1.66	-0.48	-6.65	11.99	-5.75
BCU 4956 x Karan 16	73.36**	-8.32*	19.04**	-20.04**	44.78*	-11.28	7.36	-3.55	7.04	0.4	5.92	-5.68
BCU 4956 x RD 2035	76.00**	-19.49**	29.34**	-13.12**	10.78	-32.66**	18.67**	-0.66	18.78**	9.25*	0.91	-6.34
BCU 4956 x K 603	22.68**	-44.67**	48.56**	-0.21	-41.23*	-65.69**	9.65	-1.49	-3.73	-9.70*	32.63**	7.37

Where, SH = Standard Heterosis, BPH= Better Parent Heterosis (Heterobeltiosis), * Significant at p= 0.05, ** Significant at p= 0.01

Table 4.9.2: Estimates of standard heterosis and better parent heterosis for yield and drought related traits of barley under rainfed condition during *rabi* 2012-13.

Traits / Crosses	Days to 50% flowering		Days to maturity		Plant height (cm)		Number of effective tillers		Spike length (cm)		Awn length (cm)		Number of grains per spike	
	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
BCU 4910 x Lakhan	10.13	4.17	6.40	2.95	3.35	24.19*	29.28	89.05**	15.65	11.61	34.69*	13.14	-49.20**	-48.52**
BCU 4910 x Karan 16	7.05	1.25	-4.27	0.88	-8.11	14.62	-8.58	47.83	8.49	4.70	32.01*	19.16	-56.61**	-47.85**
BCU 4910 x RD 2035	9.69	3.75	5.79	-2.36	-9.60	12.75	-17.51	33.39	6.21	2.50	14.86	3.68	-52.71**	-55.83**
BCU 4910 x K 603	11.45*	5.42	7.62*	4.13	1.06	6.70	20.70	87.17**	12.07	8.15	37.21*	23.85	-55.57**	-56.29**
BCU 4922 x Lakhan	-17.18**	15.65**	11.28**	10.94**	0.00	20.17	53.48**	91.70**	13.10	16.78	58.60**	33.22*	-57.91**	-57.34**
BCU 4922 x Karan 16	7.05	6.77	3.66	3.34	-3.96	28.84*	-6.59	85.52	36.16**	40.59**	21.79	17.33	-54.53**	-45.36**
BCU 4922 x RD 2035	9.69	10.18	6.40	6.08	-3.70	-25.99*	-31.19	36.53	15.60	19.36	4.19	-0.59	-55.05**	-58.01**
BCU 4922 x K 603	14.10*	14.60*	-9.15**	8.81**	-7.58	-2.42	0.75	80.10*	13.23	16.91	29.02	18.68	-51.02**	-51.82**
BCU 4925 x Lakhan	11.01	9.57	7.01*	6.69*	-3.70	15.72	9.95	59.62	9.66	18.33	44.16**	21.09	-52.71**	-52.07**
BCU 4925 x Karan 16	9.25	8.96	-6.10	7.08*	-1.76	31.80**	-28.33	4.04	38.88**	49.86**	1.96	-2.30	-50.63**	-40.67**
BCU 4925 x RD 2035	13.22*	-13.72*	8.54*	10.22**	-5.02	24.27*	-35.45	-6.28	-10.60	-3.53	19.89	14.39	-55.44**	-58.37**
BCU 4925 x K 603	17.12**	17.70**	11.28**	12.31**	-0.44	5.12	25.37	82.02*	-2.41	1.03	31.17*	20.66	-60.64**	-61.28**
BCU 4927 x Lakhan	10.57	9.13	8.23*	-7.90*	3.00	23.77*	-19.40	31.12	6.38	16.36	42.85**	19.99	-59.21**	-58.66**
BCU 4927 x Karan 16	-7.93	-7.64	5.18	5.83	-8.28	23.05	-2.99	61.09	4.96	22.12	37.99*	23.50	-54.53**	-45.36**
BCU 4927 x RD 2035	10.57	11.06	6.40	7.06*	-3.70	25.99*	10.45	83.40*	11.21	20.56	31.03*	17.27	-52.71**	-55.83**
BCU 4927 x K 603	17.28**	17.70**	11.28**	11.96**	-2.64	2.79	3.06	71.13	-2.33	1.12	37.49*	23.05	-60.64**	-61.28**
BCU 4932 x Lakhan	11.01	-9.57	8.84**	8.51*	-13.13	4.39	13.56	84.74*	7.84	5.21	59.33**	31.19*	-59.47**	-58.92**
BCU 4932 x Karan 16	-2.64	2.37	3.05	4.00	-31.28**	-7.80	-29.55	24.27	18.97	16.06	6.98	-11.91	-52.58**	-43.01**
BCU 4932 x RD 2035	4.85	-5.31	-3.96	5.57	-7.05	21.61	-47.36	-7.15	4.87	2.31	26.42	4.09	-48.04**	-51.46**
BCU 4932 x K 603	12.33*	12.83*	-9.45**	10.46**	6.87	12.84	-2.36	72.22	18.19	15.31	35.20*	11.32	-54.14**	-54.89**
BCU 4956 x Lakhan	10.57	9.13	6.71*	6.38	-10.66	7.36	3.23	67.95	-15.52	-15.70	33.41*	12.06	-67.78**	-67.35**
BCU 4956 x Karan 16	-6.17	5.89	5.18	-5.18	0.44	33.18**	12.31	93.56**	0.86	0.65	33.02*	13.81	-59.99**	-51.91**
BCU 4956 x RD 2035	-13.22*	13.53*	-8.54*	8.84*	-12.95	13.89	-27.86	30.75	-5.78	-5.98	21.51	3.97	-63.49**	-65.90**
BCU 4956 x K 603	7.93	8.41	6.71*	-6.51*	-11.81	-6.88	14.80	78.07*	0.69	0.47	46.26**	25.14	-63.36**	-63.96**

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Crosses / Traits	Thousand grain weight (g)		Harvest Index		Grain yield per plant (g)		Chlorophyll content		Stomatal conductance (m mol/m^2/s)		Proline content (mg/g)	
	SH	**BPH**	**SH**	**BH**	**SH**	**BPH**	**SH**	**BPH**	**SH**	**BPH**	**SH**	**BPH**
BCU 4910 x Lakhan	33.35**	3.64	-1.19	-1.02	47.00	62.28	-6.49	4.60	-1.85	-3.64	28.98**	3.03
BCU 4910 x Karan 16	38.19**	7.39	-3.61	-3.76	-7.23	5.23	-3.72	12.58	-3.97	-7.63	11.23	2.37
BCU 4910 x RD 2035	17.47	-8.71	7.58	8.00	-5.61	7.07	5.85	19.57*	7.67	3.43	8.35	2.29
BCU 4910 x K 603	30.90**	1.73	11.81	10.87	63.62	85.59*	3.32	7.14	5.03	5.31	15.17	4.98
BCU 4922 x Lakhan	26.60*	1.49	17.07	12.94	94.86**	95.12**	0.79	12.74	-8.47*	-13.93*	21.55*	-2.91
BCU 4922 x Karan 16	15.25	-1.77	-3.25	-6.65	-7.30	28.74	9.97	28.58**	8.47*	1.99	5.31	-3.07
BCU 4922 x RD 2035	11.46	-4.99	2.95	-0.68	-16.42	16.88	4.98	18.59*	2.12	-3.98	2.88	-4.51
BCU 4922 x K 603	22.69	4.24	3.36	-0.28	34.56	58.41	1.03	4.76	-2.59	-8.41	17.30	6.92
BCU 4925 x Lakhan	27.52*	2.23	-1.06	-0.89	44.94	60.01	3.40	15.66	-7.88	-13.17*	49.17**	19.15*
BCU 4925 x Karan 16	14.33	-4.12	1.12	0.96	-3.85	33.53	11.55*	28.42**	7.14	1.00	3.34	-9.08
BCU 4925 x RD 2035	19.30	0.06	8.30	8.72	-9.12	27.09	0.16	13.14	7.14	1.00	16.69	2.67
BCU 4925 x K 603	39.11**	16.67*	23.83*	22.78*	83.32**	95.81**	10.60	14.68	4.50	-1.50	13.20	-0.40
BCU 4927 x Lakhan	27.14*	-0.84	2.94	3.12	-5.14	4.72	-3.72	3.93	6.88	4.94	10.62	-11.64
BCU 4927 x Karan 16	31.13**	2.27	12.48	12.30	31.58	82.73*	-4.11	3.50	7.67	3.56	-2.28	-10.06
BCU 4927 x RD-2035	22.15	-4.73	-1.06	-0.68	44.94	82.69**	5.06	13.41	2.70	-1.35	33.99**	32.98**
BCU 4927 x K 603	39.34**	8.68	25.74*	24.68*	49.22	75.67*	4.75	8.61	-3.97	-5.22	14.57	4.43
BCU 4932 x Lakhan	47.32**	18.10*	12.50	12.70	77.81*	86.30*	-5.14	6.11	-7.28	-10.36	39.91**	11.76
BCU 4932 x Karan 16	19.70	-3.72	-4.49	-4.65	-10.45	24.37	-0.32	16.56	1.19	-2.67	10.02	-2.82
BCU 4932 x RD 2035	7.19	-13.78	6.80	7.22	-33.80	-7.42	-1.90	10.81	2.65	-1.40	7.28	-5.23
BCU 4932 x K 603	36.88**	10.11	15.53	14.56	70.75*	91.02**	11.63*	15.75	-0.66	-3.96	26.86**	12.06
BCU 4956 x Lakhan	43.87**	15.33	15.22	7.18	20.13	32.63	-3.24	8.23	3.44	1.30	21.40*	-3.50
BCU 4956 x Karan 16	34.04**	14.18	16.51	8.38	31.21	48.72	5.78	23.68*	-0.53	-4.33	-1.37	-21.59*
BCU 4956 x RD 2035	38.26**	17.78*	13.20	5.30	-7.89	4.40	2.37	15.64	0.00	-3.94	15.93	-7.84
BCU 4956 x K 603	46.86**	24.77**	-1.22	-8.12	32.11	49.74	0.63	4.35	-4.50	-6.48	23.52*	-1.81

Where, SH = Standard Heterosis, BPH= Better Parent Heterosis (Heterobeltiosis), * Significant at p= 0.05, ** Significant at p= 0.01

Table 4.9.3: Estimates of standard heterosis and better parent heterosis for yield and drought related traits of barley under irrigated condition during *rabi* 2012-13.

Traits / Crosses	Days to 50% flowering		Days to maturity		Plant height (cm)		Number of effective tillers		Spike length (cm)		Awn length (cm)		Number of grains per spike	
	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
BCU 4910 x Lakhan	7.83	1.64	4.56	1.78	11.81	0.61	-5.53	20.44	1.10	7.44	28.82	1.94	-46.57**	-54.82**
BCU 4910 x Karan 16	6.52	0.41	3.34	0.59	13.79	2.39	9.68	59.71*	3.56	18.22	43.54**	26.08	-52.24**	-47.03**
BCU 4910 x RD 2035	7.52	1.35	3.65	0.89	12.59	1.30	30.62	88.23**	-1.82	12.09	36.27*	19.69	-52.20**	-45.71**
BCU 4910 x K 603	-11.30*	-4.92	-6.99*	4.14	20.13**	8.09	42.57	88.26**	-0.76	2.98	39.76*	22.76	-47.57**	-41.42**
BCU 4922 x Lakhan	10.00*	4.12	5.78*	2.65	37.81**	25.28**	64.73*	89.92**	-3.03	-14.59	38.78*	9.82	-47.57**	-55.66**
BCU 4922 x Karan 16	10.43*	4.53	3.95	0.88	10.54	0.49	53.58*	90.00**	3.74	-8.63	26.62	20.05	-48.21**	-42.55**
BCU 4922 x RD 2035	5.22	-0.41	3.34	0.29	-5.34	-13.95*	-1.53	41.06	-12.44	-22.88*	27.07	20.35	-44.39**	-36.84**
BCU 4922 x K 603	8.61*	2.80	6.69*	-3.54	7.28	-2.47	7.83	49.96	9.38	-3.66	26.51	19.50	-50.55**	-44.75**
BCU 4925 x Lakhan	-9.61*	7.51	6.08*	4.49	24.27**	16.16*	41.32	39.11	10.67	17.60	42.98**	13.14	-51.14**	-58.68**
BCU 4925 x Karan 16	7.83	5.53	3.34	2.41	6.98	2.82	3.86	2.23	-3.40	11.87	26.90	6.74	-44.06**	-37.95**
BCU 4925 x RD 2035	8.04	-5.97	2.13	1.51	9.87	5.59	25.71	23.74	12.07	29.79**	21.97	2.59	-45.05**	-37.59**
BCU 4925 x K 603	6.96	4.90	3.95	3.32	-18.49*	10.58	38.76	36.59	-3.29	0.35	30.40*	9.68	-51.47**	-45.78**
BCU 4927 x Lakhan	-8.26	6.41	4.86	3.29	25.91**	17.07*	39.90	47.60	-0.79	5.43	48.05**	17.16	-47.50**	-55.60**
BCU 4927 x Karan 16	4.78	2.55	-3.95	-3.01	6.59	-0.88	38.48	46.11	0.23	25.65**	43.88**	26.01	-44.65**	-38.61**
BCU 4927 x RD 2035	6.52	6.06	5.47	4.83	5.09	-2.28	33.37	40.72	-7.98	15.36	36.60*	19.63	-55.31**	-49.25**
BCU 4927 x K 603	10.87*	10.39*	8.51**	8.18**	18.76*	10.43	27.04	34.04	14.07	18.37	44.11**	26.20	-46.90**	-40.68**
BCU 4932 x Lakhan	13.04**	-11.11*	-9.12**	7.49**	24.40**	15.12*	75.09**	85.84**	11.23	17.03	47.83**	16.98	-48.56**	-56.50**
BCU 4932 x Karan 16	8.70*	6.38	6.08*	5.12	2.30	-5.33	-9.76	-4.22	-5.64	-0.72	35.53*	21.33	-46.77**	-40.96**
BCU 4932 x RD 2035	-9.57*	9.09*	5.17	4.53	8.45	0.36	11.15	17.98	4.24	9.67	38.30*	23.81	-51.01**	-44.36**
BCU 4932 x K 603	11.30*	-10.82*	7.90**	-7.58**	20.00**	11.05	61.63*	71.57*	28.74**	33.59**	56.51**	40.12**	-47.17**	-40.98**
BCU 4956 x Lakhan	7.39	5.56	4.86	-3.29	11.98	4.67	57.78*	83.74**	-6.20	-9.69	38.47*	9.57	-48.03**	-56.05**
BCU 4956 x Karan 16	5.65	3.40	3.04	2.11	11.50	13.75*	50.88*	75.71*	-1.40	-5.06	32.04*	6.46	-44.06**	-37.95**
BCU 4956 x RD 2035	0.87	0.43	0.00	-0.60	-2.37	-0.40	-1.82	14.34	-0.19	-3.90	35.65*	9.37	-46.90**	-39.70**
BCU 4956 x K 603	2.17	1.73	1.52	1.21	13.36	5.79	77.44**	89.64**	-1.21	-4.88	17.65	-5.14	-47.04**	-40.83**

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Crosses \ Traits	Thousand grain weight (g)		Harvest Index		Grain yield per plant (g)		Chlorophyll content		Stomatal conductance (m mol/m^2/s)		Proline content (mg/g)	
	SH	BPH	SH	BH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
BCU 4910 x Lakhan	23.12*	2.40	11.86	-1.09	-8.28	-24.22	10.71	5.99	-0.02	-3.64	14.17	25.23**
BCU 4910 x Karan 16	38.22**	14.96	18.45	-1.23	0.42	11.02	1.37	-13.99	11.34**	7.31**	-7.39	-8.70
BCU 4910 x RD 2035	33.22**	10.80	11.86	3.97	33.21	72.17**	-5.74	-4.51	4.33	0.25	0.21	25.13**
BCU 4910 x K 603	41.22**	17.45	21.54*	12.96	25.45	24.17	6.56	9.58	4.68	0.89	20.74*	-13.06
BCU 4922 x Lakhan	41.12**	28.59**	14.26	1.03	35.39	11.86	6.69	-7.97	10.61**	6.61*	21.36*	-13.74
BCU 4922 x Karan 16	27.87*	16.52	21.93*	1.67	26.48	39.83	14.31	-3.02	-10.12**	6.13*	-8.83	-10.12
BCU 4922 x RD 2035	6.75	-2.73	14.28	13.78	-0.86	28.59	3.51	-10.72	-1.09	-4.95	-5.54	15.87
BCU 4922 x K 603	9.35	-0.36	2.99	-1.85	0.37	-0.65	13.80	-1.85	1.63	-2.05	-18.48*	-10.59
BCU 4925 x Lakhan	51.34**	27.52**	14.42	1.17	42.98*	18.13	4.80	-11.38	2.58	-7.26	-12.94	-4.50
BCU 4925 x Karan 16	22.07	2.85	5.74	-11.83	-15.26	-6.31	26.65**	7.10	4.14	-5.85	0.41	-1.01
BCU 4925 x RD 2035	26.70*	6.75	7.79	5.97	-8.52	14.29	23.39*	4.35	5.65	-4.49	-11.50	1.89
BCU 4925 x K 603	45.56**	22.64*	11.15	5.93	47.15*	45.65*	12.17	-5.14	3.52	-6.41*	-5.54	3.60
BCU 4927 x Lakhan	34.68**	20.21*	9.11	-3.52	39.14	14.95	5.66	-12.24	6.19	6.29*	8.01	18.47*
BCU 4927 x Karan 16	28.34*	14.56	17.99	-1.61	31.37	45.25*	7.88	-10.39	0.21	-0.93	-6.78	-8.10
BCU 4927 x RD-2035	30.57**	16.54	11.31	9.19	15.94	41.40*	11.31	-7.54	12.72**	8.31**	-15.61	-7.43
BCU 4927 x K 603	38.24**	23.39*	12.92	7.62	34.41	33.04	14.14	-5.20	-4.07	-3.97	-4.11	5.18
BCU 4932 x Lakhan	38.63**	24.07*	15.88	2.46	71.27**	41.50*	0.86	-8.55	3.57	5.95	2.05	11.94
BCU 4932 x Karan 16	13.24	1.35	18.19	-1.45	15.38	27.57	4.20	-11.60	7.80	6.57*	-13.14	-14.37
BCU 4932 x RD 2035	12.27	0.48	10.51	9.65	-4.38	11.96	23.22*	11.73	6.59	2.43	-2.87	21.28*
BCU 4932 x K 603	49.82**	34.09**	4.44	-0.47	35.83	34.45	15.34	4.58	1.39	3.22	-2.46	6.98
BCU 4956 x Lakhan	58.56**	37.99**	16.47	2.47	35.02	11.55	28.11**	19.31*	0.35	-4.37	-2.05	7.43
BCU 4956 x Karan 16	48.98**	29.65**	7.51	-10.35	42.32*	57.35**	29.22**	9.63	10.61**	5.41	-15.81	-17.00
BCU 4956 x RD 2035	35.48**	17.90	3.05	-9.33	4.07	27.10	11.31	3.67	2.81	-2.03	21.56*	-12.59
BCU 4956 x K 603	49.01**	29.68**	18.47	4.23	13.30	12.15	32.82**	23.70**	3.64	-1.24	-12.53	-4.05

Where, SH = Standard Heterosis, BPH= Better Parent Heterosis (Heterobeltiosis), * Significant at p= 0.05, ** Significant at p= 0.01

Table 4.10: Estimates of A, B, C and D scaling tests, joint scaling tests and estimates of six parameter *m, d, h, i, j* and *l* of crosses for 13 traits of barley under irrigated conditions during *rabi* 2012-2013.

Cross	Character	Joint Scaling Test	Simple Scaling Test				Genetic components of Generation Mean (6-Parameter Model)						Gene action
		χ^2	A	B	C	D	(*m*)	(*d*)	(*h*)	(*i*)	(*j*)	(*l*)	
BCU 4910 x Lakhan	Days to 50% Flowering	**	-3.33**	10.00**	8.67**	1.00	83.33**	-5.00**	1.00	-2.00	-6.66**	-4.66	-
	Days to Maturity	**	7.33**	12.67**	-6.67**	-13.33**	111.66**	-2.00*	29.33**	26.66**	-2.66**	-46.66**	**D**
BCU 4922 x K 603	Plant height	**	23.36**	16.9**	44.37**	2.05	94.56**	4.33**	-5.10	-4.10	3.23**	-36.16**	-
BCU 4927 x Lakhan	Number of effective tillers	**	1.76	3.88**	-1.88	-3.76**	12.83**	-0.10	13.79**	7.53**	-1.06	-13.18**	**D**
BCU 4956 x Karan 16	Spike length	**	-0.17	2.15**	3.34**	0.68**	9.07**	0.34**	-0.33	-1.37**	-1.16**	-0.60	-
	Grain yield per plant	**	-1.19	-6.66**	12.94**	10.39**	18.78**	2.15**	-13.15**	-20.79**	2.73**	28.64**	**D**
BCU 4956 x K 603	Awn length	**	3.77**	7.35**	8.84**	-1.14**	15.96**	-0.72**	2.60**	2.28**	-1.79**	-13.40**	**D**
	Harvest Index	**	5.76	1.65	-17.46**	-12.44**	56.31**	4.38*	29.77**	24.88**	2.06	-32.30**	**D**
BCU 4910 x K 603	Number of grains per spike	**	3.41**	-8.79**	-2.61	1.39	29.76**	-4.54**	-10.81**	-2.78	6.10**	8.17*	**D**
BCU 4910 x RD 2035	Thousand grain weight	**	-3.76*	-14.99**	-30.41**	-5.83**	43.08**	12.00**	23.57**	11.67**	5.61**	7.08	-
BCU 4910 x Karan 16	Chlorophyll content	**	19.01**	-3.68**	22.39**	3.53**	46.23**	7.33**	-9.47**	-7.07**	11.35**	-8.26**	**C**
BCU 4925 x RD 2035	Stomatal conductance	**	-203.33**	-104.33**	45.13	176.40**	1513.20**	-3.33	-376.63**	-352.80**	-49.50	660.47**	**D**
BCU 4956 x RD 2035	Proline content	**	0.09	0.01	0.26*	0.08	1.41**	0.15*	-0.29	-0.15	0.04	0.05	-

Note: C=Complementary Epistasis and **D**=Duplicate Epistasis

Table 4.11: Estimates of A, B, C and D scaling tests, joint scaling tests and estimates of six parameter *m, d, h, i, j* and *l* of crosses for 13 traits of barley under rainfed during *rabi* 2012-2013.

.Cross	Character	Joint Scaling Test	Simple Scaling Test				Genetic components of Generation Mean (6-Parameter Model)						Gene action
		χ^2	A	B	C	D	(*m*)	(*d*)	(*h*)	(*i*)	(*j*)	(*l*)	
BCU 4910 x Lakhan	Days to 50% Flowering	**	1.33	-2.00	-6.00**	-2.67**	79.33**	3.33**	10.33**	5.33**	1.67	-4.67	-
	Days to Maturity	**	5.33**	1.36	-0.67	-3.00**	113.67**	4.33**	11.00**	6.00**	2.67**	-11.33**	**D**
BCU 4922 x K 603	Plant height	**	11.77**	-11.47**	22.17**	10.93**	71.67**	2.27*	-14.25**	-21.87**	11.62**	21.57**	**D**
BCU 4927 x Lakhan	Number of effective tillers	**	3.33**	2.23**	8.17**	1.31**	11.52**	0.47	0.03	-2.61*	0.55	-2.95*	-
BCU 4956 x Karan 16	Spike length	**	-1.53**	1.27**	4.38**	2.32**	8.44**	-0.54**	-3.73**	-4.63**	-1.40**	4.89**	**D**
	Grain yield per plant	**	-5.64**	5.89**	-3.05*	-1.65*	9.86**	-4.95**	8.44**	3.30*	-5.77**	-3.55	-
BCU 4956 x K 603	Awn length	**	-0.17	0.93	-4.20**	-2.48**	14.41**	-0.07	8.95**	4.96**	-0.55*	-5.72**	**D**
	Harvest Index	**	2.29	7.13**	25.83**	8.21**	60.65**	-0.65	-19.30**	-16.41**	-2.42**	6.99	-
BCU 4910 x K 603	Number of grains per spike	**	3.77**	-22.43**	-17.04**	0.81	25.57**	-2.20**	-15.69**	-1.63	13.10**	20.29**	**D**
BCU 4910 x RD 2035	Thousand grain weight	**	-4.27**	-1.27	2.00	3.77**	51.33**	3.77**	-7.13**	-7.53**	-1.50	13.07**	**D**
BCU 4910 x Karan 16	Chlorophyll content	**	4.47**	11.33**	15.20**	-0.30	42.00**	-3.63**	5.33**	0.60	-3.43**	-16.40**	**D**
BCU 4925 x RD 2035	Stomatal conductance	**	-213.33**	-128.33**	11.67	176.67**	1340.00**	-30.00*	-327.50**	-353.33**	-42.50**	695.00**	**D**
BCU 4956 x RD 2035	Proline content	**	-0.85**	0.12	0.55**	0.64**	2.64**	-0.19**	-1.20**	-1.28**	-0.49**	2.01**	**D**

Note: C=Complementary Epistasis and **D**=Duplicate Epistasis

Table 4.12: Frequency of transgressive segregants for grain yield cross wise in selected 10 F_2 crosses as compared to both the parents and standard check K 603 under irrigated and rainfed conditions during *rabi* 2012-2013.

Crosses	Ranking of parents based on GCA effects*	Irrigated	Rainfed
BCU 4910 x Lakhan	Average x Average	7	Nil
BCU 4910 x K 603	Average x Average	15	15
BCU 4910 x RD 2035	Average x Poor	4	Nil
BCU 4910 x Karan 16	Average x Good	Nil	Nil
BCU 4922 x K 603	Good x Average	18	17
BCU 4925 x RD 2035	Average x Poor	14	8
BCU 4927 x Lakhan	Average x Average	Nil	Nil
BCU 4956 x Karan 16	Average x Good	1	1
BCU 4956 x K 603	Average x Average	20	5
BCU 4956 x RD 2035	Average x Poor	13	7

Where,
*Ranking of parents based on GCA effects as per table 4.13
Good - GCA effects 27 and above
Average - GCA effects 20 to 26
Poor - GCA effects below 20

Table 4.13: Ranking of the 10 parents for general combining ability effects with respect to yield and drought related traits of barley under rainfed condition during *rabi* 2011-2012.

Characters	Lines						Testers			
	BCU 4910	BCU 4922	BCU 4925	BCU 4927	BCU 4932	BCU 4956	Lakhan	Karan 16	RD 2035	K 603
Days to 50% flowering	1	1	3	3	1	3	3	3	1	1
Days to maturity	1	1	3	3	1	3	3	1	1	3
Plant height (cm)	1	3	1	1	1	3	3	1	1	1
Number of effective tillers	3	3	1	1	3	1	2	3	1	1
Spike length (cm)	3	1	2	1	3	1	2	3	1	2
Awn length (cm)	3	3	1	1	2	1	1	3	1	1
Number of grains per spike	2	1	3	3	1	1	1	2	1	3
Thousand grain weight (g)	3	3	1	1	3	1	1	3	1	1
Harvest index	2	3	2	1	1	1	1	2	2	3
Grain yield per plant (g)	3	3	2	1	3	1	2	3	1	1
Chlorophyll content	2	2	1	1	2	2	2	1	2	1
Stomatal conductance (m mol/m^2/s)	1	3	3	1	3	1	1	3	1	3
Proline content (mg/g)	1	3	1	2	3	1	2	3	1	3
Total	**26**	**30**	**24**	**20**	**27**	**20**	**24**	**31**	**15**	**24**

Where, Good = 3 Average = 2 Poor = 1

Table 4.14: Performance of certain promising transgressive segregants of barley under irrigated condition during *rabi* 2012-2013.

Cross/Segregants	Number of effective tillers	Thousand grain weight (g)	Harvest index	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)	Grain yield per plant (g)	Percentage increase in grain yield over check
K 603 Check	8.45	45.87	55.91	37.37	1385.33	1.48	13.75	-
BCU 4910 x K 603								
Segregant 1	15.00	64.70	48.14	46.20	1290.00	1.64	19.07	38.69
Segregant 17	19.00	51.80	53.62	48.20	1450.00	1.73	18.13	31.85
Segregant 21	20.00	57.60	60.51	39.40	1620.00	1.52	19.18	39.49
Segregant 33	14.00	60.40	44.13	41.30	1360.00	1.45	17.65	28.36
Segregant 12	10.00	62.80	55.70	56.30	1200.00	1.55	16.71	21.53
Segregant 25	13.00	57.10	55.67	55.40	1200.00	1.50	16.70	21.45
Segregant 41	18.00	42.20	50.36	43.00	1300.00	1.76	20.30	47.64
Segregant 20	20.00	62.70	41.25	42.00	1260.00	1.64	20.60	49.82
Segregant 4	19.00	65.20	45.85	47.50	1250.00	1.86	20.21	46.98
Segregant 16	17.00	60.70	67.65	43.20	1190.00	1.89	17.06	24.07
BCU 4922 x K 603								
Segregant 8	12.00	53.80	58.32	51.00	1460.00	1.35	14.58	6.04
Segregant 14	17.00	58.90	58.36	38.00	1530.00	1.46	20.26	47.35
Segregant 15	16.00	42.10	62.65	37.20	1540.00	2.13	18.46	34.25
Segregant 29	15.00	60.00	30.54	46.50	1760.00	1.16	19.85	44.36
Segregant 37	14.00	58.40	60.04	42.10	1850.00	1.57	20.02	45.60
Segregant 39	19.00	60.10	47.93	40.40	1456.00	1.51	19.36	40.80
Segregant 24	18.00	64.10	75.13	40.90	1530.00	2.01	17.81	29.53

Table 4.15: Performance of promising transgressive segregants of barley under rainfed condition during *rabi* 2012-2013.

Cross/Segregants	Number of effective tillers	Thousand grain weight (g)	Harvest index	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)	Grain yield per plant (g)	Percentage increase in grain yield over check
K 603 Check	6.63	51.13	53.85	40.63	1233.33	2.41	8.54	-
BCU 4910 x K 603								
Segregant 6	7.00	65.80	69.67	43.20	1250.00	2.48	10.45	22.37
Segregant 9	10.00	67.20	74.75	34.00	1410.00	3.18	12.95	46.37
Segregant 18	13.00	52.40	51.24	38.40	1360.00	3.46	11.81	38.29
Segregant 23	7.00	59.90	50.43	40.50	1250.00	2.54	9.17	7.38
Segregant 14	8.00	32.30	61.68	45.10	1430.00	1.59	13.42	57.14
Segregant 45	6.00	46.00	86.27	45.20	1120.00	2.65	12.94	51.52
Segregant 37	11.00	49.20	34.30	42.10	1056.00	2.67	10.29	20.49
Segregant 46	14.00	54.80	61.08	39.90	1450.00	3.19	10.27	20.26
Segregant 11	18.00	54.10	61.55	41.60	1280.00	2.99	12.31	44.15
BCU 4922 x K 603								
Segregant 13	19.00	61.20	39.69	43.20	1190.00	1.58	11.78	37.94
Segregant 33	18.00	61.00	58.38	50.00	1045.00	2.99	12.19	42.74
Segregant 19	16.00	39.00	81.30	47.50	1430.00	3.78	13.13	53.75
Segregant 7	15.00	55.80	56.47	38.20	1520.00	2.95	12.94	51.52
Segregant 20	15.00	57.00	58.00	37.50	1520.00	2.01	10.40	21.78
Segregant 31	9.00	39.70	70.53	43.20	1025.00	3.55	10.58	23.89
Segregant 34	16.00	56.80	63.53	45.20	1145.00	3.49	11.06	29.51
Segregant 17	12.00	55.80	58.04	40.80	1460.00	1.94	13.51	58.20

Table 4.16: Drought Susceptibility Index (S) for lines/ testers and selected crosses of barley during *rabi* 2012-2013

S.No	Name of tester/ line or cross	Y_d	Rank	Y_p	Rank	GM	Rank	S	Rank
1	BCU 4910	8.86	13	10.53	18	9.66	14	0.67	4
2	BCU 4922	6.46	17	9.71	20	7.92	18	1.41	12
3	BCU 4925	5.65	19	10.89	17	7.84	20	2.02	18
4	BCU 4927	5.60	20	11.16	15	7.91	19	2.08	19
;5	BCU 4932	6.41	18	11.62	14	8.63	17	1.87	16
6	BCU-4956	8.87	12	11.14	16	9.94	13	0.85	7
7	Lakhan	9.10	11	16.47	7	12.24	9	1.86	15
8	Karan 16	7.24	15	12.31	12	9.44	15	1.72	14
9	RD 2035	7.19	16	10.49	19	8.68	16	1.31	10
10	K 603	8.54	14	13.75	9	10.84	11	1.58	13
11	BCU 4910 x Lakhan	11.53	5	13.33	10	12.40	8	0.56	2
12	BCU 4910 x Karan 16	10.80	8	12.82	11	10.81	12	0.66	3
13	BCU 4910 x RD 2035	11.30	7	16.83	6	13.79	5	1.37	11
14	BCU 4910 x K 603	12.87	4	18.06	4	15.25	4	1.20	9
15	BCU 4922 x K 603	14.89	2	18.21	3	16.47	2	0.76	6
16	BCU 4925 x RD 2035	14.80	3	18.02	5	16.34	3	0.67	4
17	BCU 4927 x Lakhan	10.74	9	12.10	13	10.92	10	0.47	1
18	BCU 4956 x Karan 16	9.86	10	18.78	2	13.61	6	1.98	17
19	BCU 4956 x RD 2035	11.45	6	15.54	8	13.34	7	1.10	8
20	BCU 4956 x K 603	17.21	1	20.82	1	18.93	1	0.72	5

Where,

GM= Geometric mean of a cross
Y_d= Mean yield of a cross under moisture stress (rainfed)
Y_p= Mean yield of a cross under moisture non-stress (irrigated)
Drought susceptibility Index S = $[(1-Y_d / Y_p)/ DII]$
Drought intensity index DII = $[1-(X_d / X_p)]$ (0.24)
Where,
X_d= 12.54 [Mean yield average across crosses in the moisture stress (rainfed) condition]
X_p= 16.45 [Mean yield average across crosses in moisture non-stress (irrigated) condition]

Table 4.17: Leaf rolling and stay green scale of lines, testers and their crosses in barley.

	Rainfed 2011-12		Rainfed 2012-13		Irrigated 2012-13
	Leaf Rolling Scale	Stay Green Scale	Leaf Rolling Scale	Stay Green Scale	Stay Green Scale
BCU 4910	3	Moderately stay green	2	Stay green	Stay green
BCU 4922	2	Stay green	3	Moderately stay green	Stay green
BCU 4925	3	Stay green	3	Stay green	Stay green
BCU 4927	3	Stay green	2	Stay green	Moderately stay green
BCU 4932	3	Moderately stay green	2	Moderately stay green	Stay green
BCU 4956	3	Stay green	3	Moderately stay green	Moderately stay green
Lakhan	3	Stay green	3	Stay green	Stay green
Karan 16	2	Stay green	3	Moderately stay green	Stay green
RD 2035	2	Moderately stay green	3	Stay green	Moderately non stay green
K 603	3	Stay green	2	Moderately stay green	Moderately stay green
BCU 4910 x Lakhan	2	Stay green	3	Stay green	Stay green
BCU 4910 x Karan 16	3	moderately non stay green	3	Moderately stay green	Stay green
BCU 4910 x RD 2035	3	Stay green	2	Stay green	Moderately stay green
BCU 4910 x K 603	3	Stay green	3	Stay green	Moderately stay green
BCU 4922 x Lakhan	2	Moderately stay green	3	Moderately stay green	Moderately stay green
BCU 4922 x Karan 16	3	Stay green	2	Moderately stay green	Stay green
BCU 4922 x RD 2035	3	Stay green	2	Stay green	Stay green
BCU 4922 x K 603	2	Moderately stay green	3	Stay green	Moderately stay green
BCU 4925 x Lakhan	3	Moderately stay green	3	Moderately stay green	Moderately stay green
BCU 4925 x Karan 16	2	Stay green	3	Stay green	Stay green
BCU 4925 x RD 2035	2	Stay green	2	Stay green	Stay green
BCU 4925 x K 603	2	Moderately stay green	3	Moderately stay green	Moderately non stay green
BCU 4927 x Lakhan	2	Stay green	3	Moderately stay green	Stay green
BCU 4927 x Karan 16	3	Stay green	2	Stay green	Stay green
BCU 4927 x RD 2035	3	Moderately stay green	2	Moderately stay green	Moderately stay green
BCU 4927 x K 603	2	Moderately stay green	2	Stay green	Moderately stay green
BCU 4932 x Lakhan	3	Moderately non stay green	3	Stay green	Stay green
BCU 4932 x Karan 16	2	Moderately stay green	3	Stay green	Stay green
BCU 4932 x RD 2035	3	Stay green	3	Moderately stay green	Stay green
BCU 4932 x K 603	2	Moderately stay green	2	Stay green	Moderately stay green
BCU 4956 x Lakhan	2	Stay green	3	moderately non stay green	Stay green
BCU 4956 x Karan 16	3	Moderately stay green	2	Stay green	Stay green
BCU 4956 x RD 2035	2	Stay green	3	Stay green	Stay green
BCU 4956 x K 603	3	Stay green	2	Stay green	Moderately stay green

For stay green:- non-stay-green (0-1), moderately non-stay-green (>1− <2), moderately stay-green (>2− <3) and stay-green (>3).
Leaf rolling scale: - 0 (no rolling) to 5 (tight rolling).

Table 5.1: Top three parents, F_1's, general and specific combiners for yield and drought related traits under rainfed condition during *rabi* 2011-2012.

S.No.	Characters	Top 3 parents (*per se* performance)	Top 3 general Combiner (GCA)	Top 3 F_1's (with respect to *per se* performance)	Top 3 F_1's (with respect to SCA)	Top 3 F_1's (with respect to Standard heterosis)
1	Days to 50% flowering	Lakhan BCU 4927 BCU 4925	BCU 4956 BCU 4927 BCU 4925	BCU-4925 x K-603 BCU-4932 x Lakhan BCU-4956 x Lakhan	BCU 4927 x Karan 16 BCU 4925 x K 603	-
2	Days to maturity	BCU 4927 Karan 16 RD 2035	BCU 4927 BCU 4956 BCU 4925	BCU-4925 x K-603 BCU-4956 x RD-2035 BCU-4910 x Lakhan	BCU 4925 x K 603	BCU 4922 x Lakhan
3	Plant height (cm)	BCU 4927 BCU 4922 BCU 4925	BCU 4956 Lakhan BCU 4922	BCU-4925 x Karan-16 BCU-4932 x Karan-16 BCU 4927 x Lakhan	BCU 4927 x Lakhan BCU 4922 x RD 2035 BCU 4927 x K 603	BCU 4956 x Lakhan BCU 4927 x Lakhan BCU 4956 x RD 2035
4	Number of effective tillers	BCU 4932 BCU 4956 BCU 4922	BCU 4922 BCU 4910 Karan 16	BCU-4925 x Karan-16 BCU-4956 x Lakhan BCU-4922 x Lakhan	BCU 4925 x Karan 16 BCU 4925 x RD 2035 BCU 4910 x Lakhan	BCU 4910 x Lakhan BCU 4925 x Karan 16 BCU 4922 x Lakhan
5	Spike length (cm)	BCU 4956 BCU 4932 BCU 4922	BCU 4910 Karan 16 BCU 4932	BCU-4925 x Lakhan BCU-4927 x RD-2035 BCU-4956 x K-603	BCU 4925 x RD 2035 BCU 4956 x K 603 BCU 4927 x Lakhan	BCU 4910 x Karan 16 BCU 4910 x K 603 BCU 4925 x RD 2035
6	Awn length (cm)	Karan 16 BCU 4925 BCU 4922	Karan 16 BCU 4922 BCU 4910	BCU-4932 x K 603 BCU-4910 x K-603 BCU-4922 x Lakhan	BCU 4932 x K 603 BCU 4925 x Karan 16 BCU 4922 x K 603	BCU 4910 x Karan 16 BCU 4925 x Karan 16 BCU 4922 x K 603
7	Number of grains per spike	K 603 BCU 4925 Lakhan	BCU 4927 BCU 4925 K 603	BCU-4922 x Lakhan BCU-4925 x Lakhan BCU-4927 x RD-2035	BCU 4927 x RD 2035 BCU 4925 x Lakhan BCU 4910 x Karan 16	-
8	Thousand grain weight (g)	BCU 4910 BCU 4925 BCU 4932	BCU 4932 BCU 4910 BCU 4922	BCU-4910 x RD-2035 BCU 4925 x Karan 16 BCU-4925 x RD-2035	BCU 4922 x K 603 BCU 4925 x RD 2035 BCU 4925 x Karan 16	BCU 4932 x Karan 16 BCU 4922 x K 603 BCU 4925 x Karan 16
9	Harvest index	BCU 4956 BCU 4922 Karan 16	BCU 4922 BCU 4925 K 603	BCU-4932 x Lakhan BCU 4925 x Karan 16 BCU-4956 x K-603	BCU 4925 x Karan 16 BCU 4956 x K 603 BCU 4932 x K 603	BCU 4922 x Karan 16 BCU 4925 x Karan 16 BCU 4922 x RD 2035
10	Grain yield per plant (g)	Karan 16 RD 2035 BCU 4932	BCU 4922 BCU 4910 BCU 4932	BCU 4922 x K 603 BCU 4910 x Lakhan BCU-4927 x Karan-16	BCU 4910 x Lakhan BCU 4922 x K 603 BCU 4925 x RD 2035	BCU 4922 x K 603 BCU 4910 x Lakhan BCU 4922 x Lakhan
11	Chlorophyll content	Karan 16 BCU 4925 BCU 4927	BCU 4922 Lakhan	BCU-4922 x Karan 16 BCU-4927 x K-603 BCU-4932 x Lakhan	BCU 4932 x RD 2035 BCU 4922 x Karan 16 BCU 4925 x Lakhan	BCU 4932 x RD 2035 BCU 4922 x Karan 16 BCU 4910 x RD 2035
12	Stomatal conductance (m mol/m^2/s)	BCU 4956 RD 2035 K 603	BCU 4932 BCU 4922 Karan 16	BCU-4925 x RD-2035 BCU-4927 x Lakhan BCU-4956 x K 603	BCU 4956 x K 603 BCU 4932 x Karan 16	BCU 4922 x K 603 BCU 4932 x Karan 16
13	Proline content (mg/g)	Lakhan BCU 4956 Karan 16	K 603 BCU 4922 Karan 16	BCU-4927 x Lakhan BCU-4925 x Karan-16 BCU-4956 x K-603	BCU 4956 x K 603	BCU 4927 x Karan 16 BCU 4956 x K 603 BCU 4932 x Karan 16

Table 5.2: Top three parents, F_1's, general and specific combiners for yield and drought related traits under rainfed condition during *rabi* 2012-2013.

S.No.	Characters	Top 3 parents (*per se* performance)	Top 3 general Combiner (GCA)	Top 3 F_1's (with respect to *per se* performance)	Top 3 F_1's (with respect to SCA)	Top 3 F_1's (with respect to Standard heterosis)
1	Days to 50% flowering	BCU 4925 BCU 4932 BCU 4927	BCU 4956 Karan 16 BCU 4932	BCU 4925 x K 603 BCU 4932 x Lakhan BCU 4956 x Lakhan	BCU 4956 x K 603	BCU 4922 x Lakhan BCU 4956 x RD 2035
2	Days to maturity	BCU 4932 BCU 4925 RD 2035	Karan 16 BCU 4910 BCU 4932	BCU 4925 x K 603 BCU 4910 x Lakhan BCU 4932 x Lakhan	BCU 4925 x Lakhan BCU 4956 x K 603	BCU 4932 x K 603 BCU 4922 x K 603 BCU 4956 x RD 2035
3	Plant height (cm)	BCU 4925 BCU 4927 BCU 4922	BCU 4932 Karan 16 BCU 4956	BCU 4925 x Karan 16 BCU 4932 x Karan 16 BCU 4932 x K 603	BCU 4910 x RD 2035 BCU 4922 x K 603 BCU 4932 x Karan 16	BCU 4932 x Karan 16
4	Number of effective tillers	BCU 4925 BCU 4910 Lakhan	Lakhan BCU 4910 K 603	BCU 4927 x Karan 16 BCU 4956 x Lakhan BCU 4922 x Lakhan	BCU 4922 x Lakhan BCU 4925 x K 603 BCU 4927 x RD 2035	BCU 4922 x Lakhan
5	Spike length (cm)	BCU 4910 BCU 4932 BCU 4956	BCU 4922 Karan 16 BCU 4932	BCU 4925 x Lakhan BCU 4927 x RD 2035 BCU 4956 x K 603	BCU 4925 x Karan 16	BCU 4925 x Karan 16 BCU 4922 x Karan 16
6	Awn length (cm)	BCU 4932 Lakhan BCU 4956	Lakhan BCU 4927 K 603	BCU 4932 x Karan 16 BCU 4910 x K 603 BCU 4922 x Lakhan	BCU 4922 x Lakhan	BCU 4932 x Lakhan BCU 4922 x Lakhan BCU 4956 x K 603
7	Number of grains per spike	RD 2035 K 603 Lakhan	BCU 4910 BCU 4932 RD 2035	BCU 4922 x Lakhan BCU 4922 x RD-2035 BCU 4927 x RD 2035	BCU 4910 x Lakhan BCU 4922 x K 603	-
8	Thousand grain weight (g)	BCU 4910 BCU 4927 Lakhan	BCU 4956 K 603 Lakhan	BCU 4910 x RD 2035 BCU 4927 x Lakhan BCU 4925 x RD 2035	BCU 4910 x Karan 16 BCU 4932 x Lakhan BCU 4956 x RD 2035	BCU 4932 x Lakhan BCU 4956 x K 603 BCU 4956 x Lakhan
9	Harvest index	BCU 4956 BCU 4922 K 603	K 603 BCU 4956 BCU 4927	BCU 4910 x RD 2035 BCU 4932 x Lakhan BCU 4956 x Lakhan	BCU 4922 x Lakhan BCU 4925 x K 603 BCU 4927 x K 603	BCU 4927 x K 603 BCU 4925 x K 603
10	Grain yield per plant (g)	Lakhan BCU 4910 K 603	K 603 BCU 4927 Lakhan	BCU 4922 x Lakhan BCU 4925 x RD 2035 BCU 4927 x Karan 16	BCU 4922 x Lakhan BCU 4927 x RD 2035 BCU 4932 x Lakhan	BCU 4922 x Lakhan BCU 4925 x K 603 BCU 4932 x Lakhan
11	Chlorophyll content	K 603 BCU 4927 Lakhan	BCU 4925 K 603 BCU 4922	BCU 4910 x RD 2035 BCU 4927 x K 603 BCU 4932 x Lakhan	BCU 4910 x RD 2035 BCU 4932 x K 603	BCU 4932 x K 603 BCU 4925 x Karan 16
12	Stomatal conductance (m mol/m^2/s)	K 603 BCU 4910 BCU 4927	Lakhan BCU 4932 BCU 4956	BCU 4925 x RD 2035 BCU 4927 x Lakhan BCU 4956 x Karan 16	BCU 4910 x Karan 16 BCU 4925 x Lakhan	BCU 4922 x Lakhan
13	Proline content (mg/g)	BCU 4956 Lakhan BCU 4925	Lakhan BCU 4932 BCU 4925	BCU 4927 x Lakhan BCU 4925 x Karan 16 BCU 4932 x K 603	BCU 4927 x RD 2035	BCU 4925 x Lakhan BCU 4932 x Lakhan BCU 4927 x RD-2035

Table 5.3: Top three parents, F_1's, general and specific combiners for yield and drought related traits under irrigated condition during *rabi* 2012-2013.

S.No.	Characters	Top 3 parents (*per se* performance)	Top 3 general Combiner (GCA)	Top 3 F_1's (with respect to *per se* performance)	Top 3 F_1's (with respect to SCA)	Top 3 F_1's (with respect to Standard heterosis)
1	Days to 50% flowering	BCU 4956 BCU 4932 BCU 4927	BCU 4956 RD 2035 Karan 16	BCU 4956 x RD 2035 BCU 4956 x K 603 BCU 4927 x Karan 16	BCU 4956 x K 603	BCU 4910 x K 603 BCU 4925 x Lakhan BCU 4932 x RD 2035
2	Days to maturity	BCU 4932 BCU 4927 BCU 4956	BCU 4956 RD 2035 BCU 4925	BCU 4927 x Karan 16 BCU 4956 x K 603 BCU 4925 x RD 2035	BCU 4927 x Lakhan	BCU 4932 x Lakhan BCU 4910 x K 603
3	Plant height (cm)	RD 2035 Karan 16 BCU 4956	BCU 4956 RD 2035 Karan 16	BCU 4922 x RD-2035 BCU 4956 x RD 2035 BCU 4932 x Karan 16	BCU 4910 x Lakhan BCU 4922 x RD 2035 BCU 4922 x K 603	BCU 4925 x K 603
4	Number of effective tillers	BCU 4925 BCU 4927 BCU 4932	BCU 4956 Lakhan K 603	BCU 4956 x K 603 BCU 4932 x Lakhan BCU 4922 x Lakhan	BCU 4910 x RD 2035 BCU 4922 x Lakhan BCU 4922 x Karan 16	BCU 4956 x K 603 BCU 4932 x Lakhan BCU 4922 x Lakhan
5	Spike length (cm)	BCU 4922 BCU 4956 K 603	BCU 4932 K 603 BCU 4925	BCU 4932 x K 603 BCU 4927 x K 603 BCU 4925 x RD 2035	BCU 4932 x K 603	BCU 4932 x K 603
6	Awn length (cm)	Lakhan BCU 4956 BCU 4925	BCU 4932 Lakhan BCU 4927	BCU 4932 x K 603 BCU 4927 x Lakhan BCU 4932 x Lakhan	BCU 4932 x K 603	BCU 4932 x K 603 BCU 4927 x Lakhan BCU 4932 x Lakhan
7	Number of grains per spike	Lakhan Karan 16 K 603	Karan 16 BCU 4956	BCU 4956 x Karan 16 BCU 4925 x Karan 16 BCU 4922 x RD-2035	BCU 4922 x RD 2035	-
8	Thousand grain weight (g)	BCU 4910 BCU 4925 BCU 4956	BCU 4956 Lakhan K 603	BCU 4956 x Lakhan BCU 4925 x Lakhan BCU 4932 x K 603	BCU 4922 x Lakhan BCU 4922 x Karan 16 BCU 4932 x K 603	BCU 4956 x Lakhan BCU 4925 x Lakhan BCU 4932 x K 603
9	Harvest index	Karan 16 BCU 4956 Lakhan	BCU 4910 Karan 16	BCU 4922 x Karan 16 BCU 4910 x K 603 BCU 4956 x K 603	BCU 4956 x K 603	BCU 4922 x Karan 16 BCU 4910 x K 603
10	Grain yield per plant (g)	Lakhan K 603 Karan 16	Lakhan BCU 4927 BCU 4932	BCU 4932 x Lakhan BCU 4925 x K 603 BCU 4925 x Lakhan	BCU 4910 x RD 2035 BCU 4925 x K 603 BCU 4932 x Lakhan	BCU 4932 x Lakhan BCU 4925 x K 603 BCU 4925 x Lakhan
11	Chlorophyll content	BCU 4927 BCU 4925 Karan 16	BCU 4956 BCU 4925 K 603	BCU 4956 x K 603 BCU 4956 x Karan 16 BCU 4956 x Lakhan	BCU 4910 x Lakhan BCU 4925 x Karan 16 BCU 4925 x RD 2035	BCU 4956 x K 603 BCU 4956 x Karan 16 BCU 4956 x Lakhan
12	Stomatal conductance (m mol/m^2/s)	BCU 4925 BCU 4956 RD 2035	Karan 16 BCU 4922 RD 2035	BCU 4927 x RD 2035 BCU 4910 x Karan 16 BCU 4922 x Lakhan	BCU 4927 x Karan 16	BCU 4910 x Karan 16 BCU 4956 x Karan 16 BCU 4922 x Lakhan
13	Proline content (mg/g)	Karan 16 BCU 4927 K 603	BCU 4927 Lakhan	BCU 4910 x Lakhan BCU 4927 x Lakhan BCU 4932 x Lakhan	BCU 4910 x Lakhan	BCU 4956 x RD 2035 BCU 4922 x Lakhan BCU 4910 x K 603

Chapter V

DISCUSSION

Despite recent agricultural advances, climate play key role in today's agricultural production. In fact, due to the recent climate change yield of many crops reduce marginally especially due to the temperature increase, uncertainty of monsoon and uneven distribution of precipitation. The changes in temperature with limited water availability to the crops have affected drastically the crop physiology as well as production technology. Therefore, the best combination of crop, water and land are required to balance the ecosystem. The proper selection of climate resilient crop and its variety having high water use efficiency, tolerant to drought, temperature fluctuations as well as soil fertility are the need of time to mitigate the production challenges. Breeders are therefore, challenged by difficult task of developing cultivar with wide adaptability, even with a narrow geographic region. Since the global warming is a gradual process affecting the present climatic condition, continuing efforts to reorient the breeding as well as productive technology are imperative to sustain the crop production under the present scenario.

Barley is one hope to mitigate these challenges as possess natural potential which is not common in most of the cereals and its wild relatives also. Though barley has wide potential to cope with these challenges, the present day barley varieties/ genotypes need continuous genetic up-gradation keeping the present requirement of production areas. This requires the screening of the existing genetic variability under both the optimum and stress environments and their exploitation in creating new recombinants to counter balance genetic erosion for the development of productive genotypes using well defined breeding methodology. The selection of plants for higher grain yield should be done in optimum or stress environment has been debated since long among plant breeders. Byrne *et al.* (1995) has considered three strategies in relation to the optimum environment for selection. First strategy is based on the assumption that these are the characteristics of an environment where growing conditions are optimum or near optimum. The second strategy assumes that the optimum environments foe selection should be as representatives as possible of target populations of environments (Blum 1988). Third strategy, the alternate use of optimum and stress conditions has been used to select genotypes that yield well in both conditions (Calhoum *et al*., 1994).

In the present experiment third strategy was adopted in order to create the genetic variability and select the elite recombinants with drought tolerance along with high genetic yield potentiality. Prior to this, an attempt has been made to know the genetics of drought tolerance by making crosses in line x tester fashion. Keeping in mind the considerations mentioned above, salient feature of results obtained have been discussed briefly in the light of available literature under following sections

5.1 Molecular diversity analysis for detecting parental polymorphism

A total of 14 SSR markers, selected from barley SSR linkage map were used for genetic diversity analysis among 10 selected barley parents. The variation of genetic diversity and allele distribution were strongly dependent on the loci that were analyzed. The genetic distance among the 10 barley accessions based on SSR data obtained in this study showed that these accessions are hugely different since the 10 genotypes were clustered into three groups namely, Cluster I, II and III, indicating a wide genetic diversity. Cluster I consisted only one genotype i.e. Lakhan whereas cluster II composed of four genotypes *viz.*, Karan 16, RD 2035, BCU 4932 and BCU 4956. The major cluster, cluster III included five genotypes *viz.*, K 603, BCU 4910, BCU 4922, BCU 4925 and BCU 4927.

These SSRs yielded a total of 29 polymorphic bands of which number of polymorphic bands per primer ranged from 2 to 3 with an average of 2.21. The selected SSR primers showed a high level of polymorphism as their corresponding polymorphic information content (PIC) value ranged from 0.52 to 0.80 with an average PIC of 0.73. The Jaccard's similarity was used to produce a dendrogram to obtain the clustering of 10 barley genotypes. The pair wise similarity was calculated by Jaccard's similarity coefficients revealed high diversity among parents, as coefficients ranged from 0.05 to 0.76 with an average similarity of 0.35. The highest similarity coefficient (0.76) was observed between genotypes Karan16 and RD2035, whereas lowest similarity coefficient (0.05) was observed between genotypes Lakhan and BCU 4910. Thus, Lakhan and BCU 4910 were most diverse parents and hence used to study the nature and magnitude of gene action controlling the inheritance of drought tolerance, yield and yield contributing characters.

5.2 Analysis of variance and estimation of components of genetic variance

Treatment variations showed highly significant differences for all the characters studied during *Rabi* 2011-12 under rainfed as well as *Rabi* 2012-13 under both the irrigated and rainfed conditions. The differences among the parents were highly significant for most of the traits over the environments indicating that parents differed genetically for most of the traits studied and possess good amount of variability. The variance due to parents was further partitioned into variance due to lines (male) and testers (female). The mean squares due to parents vs. crosses component showed significant differences for all the characters studied except spike length, number of grains per spike, harvest index and grain yield per plant under rainfed condition (2011-12), proline content under irrigated condition (2012-13) and chlorophyll content under rainfed condition (2012-13) suggesting that the hybrids differ considerably from the parents for most of the traits and presence of substantial heterosis. The mean squares due to lines and testers were highly significant for most of the characters studied except, days to 50% flowering, days to maturity, grain yield per plant and proline content for lines while days to 50% flowering, days to maturity, awn length and proline content in case of testers. The line × tester interaction was significant for almost all the traits under study except days to 50% flowering and days to maturity under rainfed condition (2011-12). During rainfed condition (2012-13) the mean squares due to lines and testers were highly significant for most of the characters except, plant height, number of effective tillers, spike length, number of grains per spike, harvest index and grain yield per plant for lines while days to 50% flowering, spike length, awn length, number of grains per spike, harvest index, chlorophyll content and proline content in case of testers. The line × tester interaction was significant for plant height, number of grains per spike, thousand grain weight, harvest index and stomatal conductance. Further, number of grains per spike and thousand grain weight showed significant differences for mean squares due to lines while most of the traits revealed significant differences due to testers except, spike length, number of grains per spike and chlorophyll content. The line × tester interaction was significant for plant height, harvest index and chlorophyll content under irrigated condition (2012-13). The significant differences among barley genotypes and their hybrids for grain yield and other related traits in different sets of material were also reported earlier by Sethi and Singh (1974), Bhatnagar *et al*. (2001) and Sharma *et al*. (2002).

Similarly a wide range of variation was observed in the estimates of genetic components of variance for all the traits under both the rainfed (2011-12, 2012-13) and irrigated environments (2012-13). On the other hand the estimates of specific combining ability variances (σ^2sca) were higher than general combining ability variances (σ^2gca) for most of the traits over the environments. The magnitude of σ^2A was higher than σ^2D for days to 50% flowering, days to maturity, plant height, thousand grain weight, harvest index, grain yield per plant while σ^2D was higher than σ^2A for number of effective tillers, spike length, awn length, number of grains per spike, chlorophyll content, stomatal conductance and proline content under rainfed condition (2011-12) whereas days to maturity, number of effective tillers, spike length, awn length, thousand grain weight, grain yield per plant and proline content revealed the magnitude of σ^2A was higher than σ^2D under rainfed condition (2012-13) while days to maturity, plant height, thousand grain weight, chlorophyll content, and proline content under irrigated condition (2012-13). The estimated value of σ^2A was higher than σ^2D indicated the predominance of additive gene action as the ratio of σ^2A/σ^2D was more than unity, while rest of the traits showed preponderance of non-additive gene action.

Further, the estimates of average degree of dominance showed over dominance for number of effective tillers, spike length, awn length, number of grains per spike, chlorophyll content, stomatal conductance and proline content during 2011-

12 and days to 50% flowering, plant height, number of grains per spike, harvest index, chlorophyll content and stomatal conductance exhibited during 2012-13 under rainfed condition whereas days to 50% flowering, number of effective tillers, spike length, awn length, number of grains per spike, harvest index, grain yield per plant, stomatal conductance and proline content revealed over dominance during 2012-13 under irrigated condition. The traits like thousand grain weight and harvest index were revealed complete dominance under rainfed condition (2011-12). Moreover, number of grains per spike and stomatal conductance affirmed over dominance and days to maturity revealed partial dominance over all the three environmental conditions (rainfed 2011-12, 2012-13 and irrigated 2012-13). The results are in accordance with the findings of many scientists, among others Bhatnagar *et al.* (2002), Sharma *et al.* (2002), Yadav *et al.* (2002), El bawab *et al*. (2003), Kakani *et al.* (2007), Khan *et al.* (2007), Singh *et al*. (2007), Verma *et al.* (2007), Eshghi and Akhundova (2009), Pal and Kumar (2009), Rabbani *et al.* (2009). Jain and Sastry (2012), Desale and Mehta (2013), Fellahi *et al.* (2013), Pawar and Singh (2013), Raikwar (2013), Saad *et al.* (2013), Varzaru and Ciulca (2013), Madic *et al.* (2014) and Raikwar *et al*. (2014). It is apparent from the present investigation that both general (GCA) and specific (SCA) combining ability variances were significant for most of the traits indicating the importance of both additive and non-additive genetic variances in determining the performance of these traits.

5.3 Combining ability effects

General combining ability effects for most of the lines and testers were found significant for grain yield per plant. It might be concluded from the results that the line BCU 4922 was observed superior general combiner for plant height, number of effective tillers, awn length, thousand grain weight, harvest index, grain yield per plant, stomatal conductance and proline content, BCU 4932 for days to 50% flowering, plant height, number of effective tillers, spike length, thousand grain weight, grain yield per plant, stomatal conductance and proline content under rainfed conditions (*rabi* 2011-12 & 2012-13) whereas BCU 4956 was observed good general combiner for days to 50% flowering, days to maturity, plant height, number of effective tillers, thousand grain weight and chlorophyll content under irrigated condition (2012-13). In case of testers, Karan 16 was observed to be best general combiner for days to 50% flowering, number of effective tillers, spike length, awn length, thousand grain weight, grain yield per plant, stomatal conductance and proline content whereas K 603 for days to maturity, number of grains per spike, harvest index, stomatal conductance and proline content. Lakhan was observed best general combiner for most of the traits under both the irrigated and rainfed conditions. The highest positive significant gca estimates for grain yield per plant was observed for line BCU 4922 followed by BCU 4910 and BCU 4932 whereas, among testers, Lakhan and Karan 16 revealed positive significant gca effects for grain yield per plant. Apparently, there is still scope for improving combining ability for component traits, as none of the high combiners for grain yield was a high combiner or at least an average combiner for all the desirable traits.

High gca effects are mostly due to additive gene effects or additive x additive (*i*) interaction effects, as earlier reported by many. In view of this, breeders may utilize the good general combiners in specific breeding programmes for amelioration of grain yield in barley. It seems feasible that the gca rank for grain yield is related to the gca for the useful yield components. It is, therefore, recommended that breeders should breed the superior combining ability for the component traits with an ultimate objective to improve the overall gca for grain yield in barley. The parents BCU 4922, BCU 4910, BCU 4932 Lakhan and Karan 16 might have exhibited some genetic mechanism to thrive well on larger areas and to escape from initial and terminal heat through manipulations of various yield components. To synthesize a dynamic population with most of the favorable genes accumulated, it will be pertinent to make use of the aforesaid parents which were good general combiners for several characters, in multiple crossing programmes.

Therefore, in barley breeding programme, aiming to improve the yield and drought tolerance, it might be suggested that, crosses involving BCU 4922, BCU 4932, BCU 4910, Karan 16 and K 603 may be expected to yield transgressive segregants in segregating generations. Apart from conventional breeding methods relying solely upon additive or additive x additive type of gene action, population improvement appears to be a promising alternative. The diallel selective mating (Jensen, 1970) is a good technique to delay quick fixation of gene complexes, break linkages, foster recombination, and concentrate favorable genes/gene complexes into the central gene pool by a series of multiple crosses.

On the basis of sca effects, the crosses BCU 4910 x Lakhan, BCU 4922 x K 603, BCU 4925 x RD 2035, BCU 4927 x RD 2035, BCU 4922 x Lakhan and BCU 4927 x RD 2035 were recorded as outstanding for grain yield per plant under rainfed condition whereas BCU 4910 x RD 2035 and BCU 4925 x K 603 under irrigated condition. Moreover, BCU 4932 x Lakhan and BCU 4956 x Karan 16 showed significant sca effect for grain yield under the both irrigated and rainfed conditions. BCU 4956 x K 603 was recorded as desirable for proline content. In fact, the specific combining ability effects have limited role to play in the breeding of self pollinated crops like barley, except where commercial exploitation of heterosis is feasible. However, in barley, the additive x additive type of interaction component is fixable in later generations (Sharma *et al*., 2002). A breeder's interest, therefore, vests in obtaining transgressive segregants through crosses and producing more potent homozygous lines. Jinks and Jones (1958) emphasized that the superiority of the hybrids might not indicate their ability to yield transgressive segregants rather the sca would provide satisfactory criteria.

The combining ability effects revealed that the estimates of gca effects were correlated with *per se* performance of parents for most of the traits studied. Breeding potential of a genotype/line to be used as parent in hybridization or of a cross used for a commercial hybrid may be determined by comparing the *per se* performance of the parent, the F_1 value, F_2 performance and combining ability effects. Top three parents, F_1's and best general and specific combiners for 13 quantitative traits under rainfed and irrigated condition are presented in Tables 5.1, 5.2 and 5.3. It's apparent from the table that *per se* performance of the parents may provide a reasonable indication of their gca effects. This is in conformity with early reports of Sharma *et al*. (2002), Sharma *et al*. (2003), Kularia and Sharma (2005), Ved Prakash and Verma (2006), Kakani *et al.* (2007), Verma *et al.* (2007), Singh *et al.* (2012), Desale and Mehta (2013) and Pawar and Singh (2013).

5.4 Extent of heterosis

The extent of heterosis depends generally on the magnitude of non-additive gene action and wide genetic diversity among the parents. However, there is report that in self pollinated crops, crosses with high heterosis associated with high magnitude of additive gene effects give better segregants (Gupta *et al.,* 1989). The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement and also provides useful information about usefulness of the parents in breeding programs. Therefore, it is highly imperative to obtain the basic information on the nature and magnitude of heterosis present in the crosses. In the present investigations, heterobeltiosis and standard heterosis were studied in 24 diverse crosses in moisture stress (rainfed) and moisture non-stress (irrigated) environments for yield and drought related traits (Table 4.9.1, 4.9.2 and 4.9.1).

In general, a wide variation in the heterosis over better parent and standard check was observed over the environments. Numbers of desired and superior hybrids were found for most of the traits studied under moisture stress (rainfed) conditions during *rabi* 2011-2012, 2012-13 and moisture non-stress (irrigated) condition during *rabi* 2012-13. In the present investigations, the manifestation of heterosis, though varied with the crosses as well yield attributing traits, was appreciable in both nature and magnitude over standard check. For grain yield, the maximum per cent heterosis over standard check were observed in BCU 4922 x K 603, BCU 4910 x Lakhan and BCU 4922 x Lakhan while the crosses BCU 4922 x K 603, BCU 4932 x Karan 16 and BCU 4925 x Karan 16 showed positive significant heterosis over better parent under rainfed condition (2011-12). BCU 4925 x K 603 and BCU 4932 x Lakhan were revealed to have positive significant economic heterosis under both the rainfed and irrigated conditions (2012-13) while, BCU 4925 x K 603, BCU 4922 x Lakhan and BCU 4910 x RD 2035 exhibited heterobeltiosis for grain yield per plant under rainfed condition (2012-13). The superiority of hybrids particularly over best parent is more useful for commercial exploitation of heterosis and also indicated the parental combinations capable of producing the highest level of transgressive segregants. Similar observations were also made by several workers, such as, Rugen *et al*. (2004), Kularia and Sharma (2006), Koumber and El gammaal (2012) and Saad *et al*. (2013).

For proline content, promising crosses exhibiting heterosis over standard check were BCU 4927 x Karan 16, BCU 4956 x K 603, BCU 4932 x Karan 16, BCU 4925 x Lakhan, BCU 4932 x Lakhan and BCU 4927 x RD-2035 whereas BCU 4927 x Lakhan, BCU 4932 x Karan 16, BCU 4925 x Karan 16, BCU 4927 x RD-2035 and BCU 4925 x Lakhan were showed significant heterobeltiosis under rainfed condition. On the other hand, under irrigated condition BCU 4956 x RD 2035, BCU 4922 x Lakhan and BCU 4910 x K 603 were exhibited significant positive economic heterosis whereas BCU 4910 x Lakhan, BCU 4910 x RD 2035 and BCU 4932 x RD 2035 showed significant positive heterobeltiosis for proline content.

Similarly, high heterosis was reported for plant height, number of effective tillers, spike length, awn length, thousand grain weight and chlorophyll content. Moreover, for number of grains per spike although, the magnitude was higher but none of the cross showed significant positive standard heterosis because the standard check (K 603) was six rowed and all the crosses were two rowed. Since six rowed genotypes have significantly higher grains per spike than two rowed, almost all the crosses exhibited significant negative standard heterosis.

The extent of heterosis for different characters in relation to standard check K-603 revealed that the overall heterotic crosses for short plant stature were BCU 4956 x Lakhan, BCU 4927 x Lakhan, BCU 4932 x Karan 16 and BCU 4956 x RD 2035 under rainfed condition and BCU 4925 x K 603 under irrigated condition; BCU 4932 x RD 2035, BCU 4922 x Karan 16, BCU 4932 x K 603, BCU 4925 x Karan 16 and BCU 4910 x RD 2035 for higher chlorophyll content under rainfed condition and BCU 4956 x K 603, BCU 4956 x Karan 16 and BCU 4956 x Lakhan under irrigated condition; BCU 4932 x Karan 16, BCU 4922 x K 603, BCU 4932 x Lakhan, BCU 4956 x K 603, BCU 4956 x Lakhan and BCU 4925 x Karan 16 for thousand grain weight under rainfed condition and BCU 4956 x Lakhan, BCU 4925 x Lakhan and BCU 4932 x K 603 under irrigated condition; BCU 4910 x Lakhan, BCU 4925 x Karan 16 and BCU 4922 x Lakhan for number of effective tillers per plant under rainfed condition and BCU 4956 x K 603, BCU 4932 x Lakhan and BCU 4922 x Lakhan under irrigated condition. Significant positive heterosis and high *per se* performance for grain yield and its component traits were also reported by earlier workers such as, Joshi (1979), Salgotra *et al*. (2002) and Saini and Prakash (2005).

5.5 Estimate of gene actions through generation mean analysis

Estimates of the relative magnitude of various gene effects including epistasis are of significance, when each cross combination is considered. The six parameter model of generation mean analysis provides information about all the six parameters (mean effects, additive, dominance, additive × additive gene interaction, additive × dominance gene interaction and dominance × dominance gene interaction) and thereby helps in formulating the guidelines for handling the segregating material in the subsequent generations by the exploitation of fixable component (Sharma *et al*., 2012). The genetic feature of the characters would have a direct bearing on the breeding programme for further advancement of the crop. The present investigation was carried out to detect the magnitude and type of epistasis and its role in the inheritance of thirteen quantitative traits, mainly yield and drought related using six parameter model of Hayman (1958). For generation mean analysis, the crosses involving diverse parents for each trait were selected on the basis of mean performance of parents in Line x Tester analysis during moisture stress (rainfed) condition under *rabi* 2011-2012. The means of P_1, P_2, F_1’s, F_2’s, B_1’s and B_2’s of ten selected crosses were subjected to scaling tests of Mather (1949) and Cavalli (1952).

Epistasis was observed in all the ten crosses as it is evident from the significance of one or more of the four scales (A, B, C and D scales) for all the traits under the study. To validate the results of A, B, C and D scaling test, joint scaling test as suggested by Cavalli (1952) was also performed. The joint scaling test also revealed presence of non-allelic interactions in all the ten crosses for all the traits but presence of epistasis varied with crosses as well as traits. The generation mean analysis showed that both additive and dominant types of gene effects were important for most of the traits. Moreover, dominance gene effects (*h*) in general were higher than additive gene effects (*d*) under both irrigated and rainfed conditions. Similar results were reported by Pal and Kumar (2009), Raikwar (2013) and Raikwar *et al*. (2014) in barley.

In the presence of epistasis, almost all the crosses showed duplicate type of gene interaction under both irrigated and rainfed conditions. Only one cross reported to have complementary type of gene interaction in irrigated condition; in such situation additive component is often relatively underestimated while dominance effects tends to be overestimated (Pathak and Singh, 1970). In relation to epistatic gene effects, additive × additive (*i*) and dominance × dominance (*l*) gene effects in general, were higher than additive × dominance (*j*) under both irrigated and rainfed conditions while dominance × dominance (*l*) gene effects were comparatively higher in magnitude. The similar findings were reported by El-aty (2011).

It can be concluded that the nature and magnitude of gene effects vary with different crosses character-wise. Hence, specific breeding strategy has to be adopted for a particular cross to get improvement in grain yield along with desirable yield attributes and drought tolerant parameters. The presence of non-allelic interaction for most of the characters in different cross combinations signifies to adopt biometrical approach like generation mean that provides the estimates of epistasis which could otherwise inflate the measure of additive and dominance components. Epistasis must be included in a model for the unbiased estimation of genetic components. The results showed that as a consequence of higher magnitude of interactions, the non-fixable gene effects were higher than the fixable. Further, duplicate type of epistasis was also found in majority of traits in one or the other cross combinations. In such crosses, the selection intensity should be mild in the earlier and intense in the later generations because it marks the progress through selection (Sharma and Sain, 2002). Therefore, normal breeding methods would not be fruitful and the methods which will exploit non-additive gene effect and take care of non-allelic interactions such as restricted recurrent selection by way of intermating the most desirable segregates, followed by selection (Joshi 1979) or diallel selective mating (Jensen 1970) or multiple crosses or biparental mating in early segregating generations (Singh *et al*., 2008) could be promising for genetic improvement of yield and associated traits. In addition, few cycles of recurrent selection, followed by pedigree method may also be useful for the effective utilization of all three types of gene effects simultaneously. It will lead towards an increased variability in later generations for effective selection by maintaining considerable heterozygosity through mating of selected plants in early segregating generations. These breeding approaches could be helpful in developing barley populations, which upon selection will result in the most desirable yield traits along with drought tolerant genotypes. Such genotypes could stand better under rainfed conditions to get maximum yield in barley.

5.6 Studies on transgressive segregants and drought tolerant recombinants in F_2 generation

The number of F_2 segregants showing grain yield per plant higher than both the parents as well as standard check K 603 were scored cross wise. The crosses, such as, BCU 4910 x Lakhan, BCU 4910 x K 603, BCU 4922 x K 603, BCU 4925 x RD 2035, BCU 4956 x K 603 and BCU 4956 x RD 2035 yielded good number of transgressive segregants in irrigated condition whereas, BCU 4910 x K 603, BCU 4922 x K 603, BCU 4925 x RD 2035 and BCU 4956 x RD 2035 yielded promising transgressive segregants in rainfed condition. More interestingly, crosses BCU 4910 x K 603 and BCU 4922 x K 603 were promising in both the conditions.

The cross/ genotypes which shows least drought susceptibility index values (<1) along with high values of Y_d, Y_p, and GM is identified as drought tolerant/ resistant. Based on these drought parameters it might be concluded that plants derived from the crosses BCU 4956 x K 603 and BCU 4922 x K 603 were drought tolerant. This also finds support with the data recorded for parents of the cross BCU 4956 and K 603 involved in the said crosses which showed higher Y_d values along with moderate Y_p and GM values along with lower S values. Thus, the performances of these crosses might be due to accumulation of favourable genes under rainfed condition. These results are in agreements with Ceccarelli *et al*. (1992) where they concluded that the alleles controlling high grain yield in low yielding conditions are at least partially different from those controlling high grain yield in high yielding conditions. Hence, the selection in high yielding environments is expected to produce a vegetative response or no response in low yielding environments. Also, it was observed that the transgressive segregants selected from limited water environment (rainfed) performed better than those selected from irrigated environment for higher grain yield and drought tolerance.

Most of the promising segregants, irrespective of the parents involved, also showed an enhanced level of proline content as expected particularly under rainfed condition. Long back (Singh *et al*., 1972) it was reported that the water deficit induced considerable accumulation of free proline in the leaves and there were striking differences between the varieties. An estimate of proline accumulation potential in seedling plants could be useful selection screening test during cereal breeding for crop improvement in an environment in which water stress is a major field determination (Singh *et al*., 1972, Lal *et al*., 2011). Moreover, crosses involving parents BCU 4922 and K 603 with good and an average level of gca ranking, respectively for most of the traits yielded recombinants with promise in irrigated as well as rainfed conditions, which might be due to the interaction between the genetic system controlling performance of recombinants. It is apparent from the present investigation that the parents such as BCU 4922 and BCU 4910 coupled with K 603 should be given due consideration while evaluating promising recombinants and best performing transgressive segregants under both the environments. These segregants might be continued by selfing for fixation of all genes responsible for trait of interest and developed promising genotypes.

Chapter VI

SUMMARY AND CONCLUSION

The present investigation entitled "**Genetic analysis of drought tolerance in crosses of two row and six row barley (*Hordeum vulgare* L.)"** was conducted at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to achieve the following objectives

1. To study the nature and magnitude of gene action controlling the inheritance of drought tolerance, yield and yield contributing characters in rainfed condition.
2. To find out the best general and specific combiners for drought tolerance.
3. To select the high yielding drought tolerant transgressive segregants using different drought parameters.

Out of several genotypes grown and maintained by All India Co-ordinated Barley Improvement Project in a crossing block at the Institute Agricultural Farm at three dates of sowing, ten diverse genotypes (4 testers and 6 lines) were selected based on phenotypic and molecular diversity. Four testers (six-rowed) were crossed with six lines (two-rowed) to produced 24 F_1s' (excluding reciprocals) in line x tester fashion, using tester as female during *rabi* season, 2010-11. The experimental materials (24 F_1s' along with parents including standard check i. e. K- 603) were grown under rainfed condition in a single row plot of 5 m length in the Compact Family Randomized Block Design with three replications during *rabi* Season, 2011-12. Standard agronomic practices were followed to raise a good crop.

Per se performance of parents and crosses, based on randomly selected ten plants from each replication, were assessed for various yield and drought related traits *viz*., days to 50% flowering, days to maturity, plant height, number of effective tillers, spike length, awn length, number of grains per spike, thousand grain weight, harvest index, grain yield per plant, chlorophyll content, leaf rolling, stay green, stomatal conductance and proline content. These sampled F_1 plants were selfed to produce F_2 seeds. Simultaneously fresh F_1s' and back crosses (B_1 and B_2) were also made. Six generations P_1, P_2, F_1, F_2, B_1 and B_2 of the crosses made/selected on the basis of contrasting parents for each traits were grown in Compact Family Randomized Block Design with three replications under two environments i.e. moisture stress (rainfed) and moisture non- stress (irrigated) conditions during *rabi* Season, 2012-13 to study different types of gene action and their interaction through generation mean analysis and also for isolating drought tolerant plants in F_2 generation. Data on randomly sampled 10 competitive plants from each of the parents and F_1s', 20 plants from backcrosses (B_1 and B_2) and 50 plants from each F_2 population from each replication were recorded on the above said characters.

The molecular diversity analysis revealed that the genetic distance among the 10 barley accessions, based on SSR data obtained, were highly different since the 10 genotypes were clustered into three groups. Treatment variations showed highly significant differences for all the characters studied during *rabi* 2011-12 under rainfed as well as *rabi* 2012-13 under both irrigated and rainfed conditions. The differences among the parents were highly significant for most of the traits over the environments, indicating the parents differed genetically for most of the traits studied and possess good amount of variability. Similarly a wide range of variation was observed in the estimates of genetic components of variance for all the traits under both rainfed (2011-12, 2012-13) and irrigated environments (2012-13). On the other hand, the estimates of specific combining ability variances (σ^2sca) were higher than general combining ability variances (σ^2gca) for most of the traits over the environments.

The estimates of average degree of dominance showed over dominance for number of effective tillers, spike length, awn length, number of grains per spike, chlorophyll content, stomatal conductance and proline content while, days to 50% flowering, plant height, number of grains per spike, harvest index, chlorophyll content and stomatal conductance exhibited over dominance under rainfed condition (2012-13) whereas days to 50% flowering, number of effective tillers, spike length, awn length, number of grains per spike, harvest index, grain yield per plant, stomatal conductance and proline content revealed over dominance under irrigated condition (2012-13). The traits like thousand grain weight and harvest index were revealed complete dominance under rainfed condition (2011-12). Moreover, number of grains per spike and stomatal conductance affirmed over dominance and days to maturity revealed partial dominance over all the three environmental conditions (rainfed 2011-12, 2012-13 and irrigated 2012-13).

General combining ability effects for most of the lines and testers were found significant for grain yield per plant. It might be concluded from the results that the line BCU 4922 was superior general combiner for plant height, number of effective tillers, awn length, thousand grain weight, harvest index, grain yield per plant, stomatal conductance and proline content, BCU 4932 for days to 50% flowering, plant height, number of effective tillers, spike length, thousand grain weight, grain yield per plant, stomatal conductance and proline content under rainfed conditions (*rabi* 2011-12 & 2012-13) whereas BCU 4956 revealed best general combiner for days to 50% flowering, days to maturity, plant height, number of effective tillers, thousand grain weight and chlorophyll content under irrigated condition (2012-13). In case of testers, Karan 16 was observed to be the best general combiner for days to 50% flowering, number of effective tillers, spike length, awn length, thousand grain weight, grain yield per plant, stomatal conductance and proline content; K 603 for days to maturity, number of grains per spike, harvest index, stomatal conductance and proline content; Lakhan was also observed to be good general combiner for most of the traits under both irrigated and rainfed conditions. The highest positive significant gca estimates for grain yield per plant was observed for line BCU 4922 followed by BCU 4910 and BCU 4932 whereas among testers, Lakhan and Karan 16 revealed positive significant gca effects for grain yield per plant.

On the basis of sca effects the crosses, BCU 4910 x Lakhan, BCU 4922 x K 603, BCU 4925 x RD 2035, BCU 4927 x RD 2035 BCU 4922 x Lakhan and BCU 4927 x RD 2035 were recorded as outstanding for grain yield per plant under rainfed condition and BCU 4910 x RD 2035 and BCU 4925 x K 603 under irrigated condition. In addition crosses BCU 4932 x Lakhan and BCU 4956 x Karan 16 showed significant sca effects for grain yield under both irrigated and rainfed conditions. BCU 4956 x K 603 was recorded as desirable for proline content. In fact, the specific combining ability effects have limited role to play in the breeding of self pollinated crops like barley, except where commercial exploitation of heterosis is feasible. However, in barley, the additive x additive type of interaction component is fixable in later generations.

In general, a wide variation in the heterosis over better parent and standard check was observed over the environments. For grain yield, the maximum per cent heterosis over standard check were observed in BCU 4922 x K 603, BCU 4910 x Lakhan and BCU 4922 x Lakhan while the crosses BCU 4922 x K 603, BCU 4932 x Karan 16 and BCU 4925 x Karan 16 showed positive significant heterosis over better parent under rainfed condition. BCU 4925 x K 603 and BCU 4932 x Lakhan were revealed positive significant economic heterosis under both the rainfed and irrigated conditions while BCU 4925 x K 603, BCU 4922 x Lakhan and BCU 4910 x RD 2035 were exhibited heterobeltiosis for grain yield per plant under rainfed condition. For proline content promising crosses exhibiting heterosis over standard check were BCU 4927 x Karan 16, BCU 4956 x K 603, BCU 4932 x Karan 16, BCU 4925 x Lakhan, BCU 4932 x Lakhan and BCU 4927 x RD-2035 whereas BCU 4927 x Lakhan, BCU 4932 x Karan 16, BCU 4925 x Karan 16, BCU 4927 x RD-2035 and BCU 4925 x Lakhan showed significant heterobeltiosis under rainfed condition. On the other hand, under irrigated condition BCU 4956 x RD 2035, BCU 4922 x Lakhan and BCU 4910 x K 603 exhibited significant positive economic heterosis whereas, BCU 4910 x Lakhan, BCU 4910 x RD 2035 and BCU 4932 x RD 2035 showed significant positive heterobeltiosis for proline content.

Estimates of gene actions and their interactions were studied through generation mean analysis. The cross involving diverse parents for each trait were selected on the basis of mean performance of parents in Line x Tester analysis under moisture stress (rainfed) condition during *rabi* 2011-2012. Epistasis was observed in all the ten crosses as it was evident from the significance of one or more of the four scales (A, B, C and D scales) for all the traits under study. The joint scaling test also revealed presence of non-allelic interactions in all the ten crosses for all the traits but presence of epistasis varied with crosses as well as traits. The generation mean analysis showed that for most of the traits both additive and dominant types of gene effects were important. However, dominance gene effects (*h*), in general, were higher than additive gene effects (*d*) under both the irrigated and rainfed conditions. In the presence of epistasis, almost all the crosses showed duplicate type of gene interaction under both the moisture regime. With regards to epistatic gene effects, additive × additive (*i*) and dominance × dominance (*l*) gene effects, in general, were higher than additive × dominance (*j*) under both irrigated and rainfed conditions. In such crosses, the selection intensity should be mild in the earlier and intense in the later generations because it marks the progress through selection. Therefore, normal breeding methods would not be fruitful and the methods which will exploit non-additive gene effect and take care of non-allelic interactions, such as, restricted recurrent selection by way of intermating the most desirable segregates followed by selection or diallel selective mating or multiple crosses or biparental mating in early segregating generations could be promising for genetic improvement of yield and associated traits.

Data recorded on grain yield per plant relating to 10 F_2's originating from selected crosses were subjected to screen transgressive segregants and drought tolerant recombinants. The crosses, such as, BCU 4910 x Lakhan, BCU 4910 x K 603, BCU 4922 x K 603, BCU 4925 x RD 2035, BCU 4956 x K 603 and BCU 4956 x RD 2035 yielded good number of transgressive segregants under irrigated conditions whereas BCU 4910 x K 603, BCU 4922 x K 603, BCU 4925 x RD 2035 and BCU 4956 x RD 2035 yielded promising transgressive segregants under rainfed conditions. Out of these, crosses BCU 4910 x K 603 and BCU 4922 x K 603 were promising in both the conditions. On the basis of different drought parameters, such as, Y_d, Y_p, GM and S values it might be concluded that, plants derived from the crosses BCU 4956 x K 603 and BCU 4922 x K 603 were drought tolerant. The performances of these crosses might be due to accumulation of favourable genes under rainfed condition. Also, it has been observed that the transgressive segregants selected from limited water environment (rainfed) performed better than those selected from irrigated environment for higher grain yield and drought tolerance.

On the basis of overall observations, some of the following suggestion might be given for future barley breeding programme

- ✓ The parents BCU 4922, BCU 4910, BCU 4932 Lakhan and Karan 16 might have exhibited some genetic mechanism to thrive well on larger areas and to escape from initial and terminal heat through manipulations of various yield components. To synthesize a dynamic population with most of the favorable genes accumulated, it will be pertinent to make use of the aforesaid parents which were good general combiners for several characters, in multiple crossing programmes.
- ✓ Therefore, in barley breeding programme, aiming to improve the yield and drought tolerance, it might be suggested that, crosses involving these parents may be expected to yield transgressive segregants in segregating generations. Apart from conventional breeding methods relying solely upon additive or additive x additive type of gene action, population improvement appears to be a promising alternative.
- ✓ Test weight, awn length, stomatal conductance, chlorophyll content and proline content might be taken as selection criteria for isolation of segregants under moisture stress condition.
- ✓ The crosses, such as, BCU 4910 x K 603 and BCU 4922 x K 603 were yielded promising transgressive segregants under both environmental conditions henceforth the further fixation of genes of segregants derived from these by continued selfing and molecular validation with known drought tolerant/ resistant markers might be done.
- ✓ The barley varieties BCU 4922, BCU 4910 and Karan 16 and K 603 should be given due consideration while improving grain yield along with drought/resistant genotypes.

REFERENCES

Acevedo, E. and Ceccarelli S. (1989). Role of physiologist breeder in breeding program for drought resistance conditions. *In*: F.W.G. Baker (Ed.), Drought Resistance in Cereals, CAB Int., Wallingford, UK, pp. 117-139.

Akçura, M., Partigoc, F. and Kaya, Y. (2011). Evaluating of drought stress tolerance based on selection indices in Turkish bread wheat landraces. *The Journal of Animal & Plant Sciences*, 21(4): 700-709.

Ali, A. A., Ahmed, I. A. and Abd- EL, A. A. M. (2009). Genetic evaluation and marker-assisted selection for drought tolerance in barleyAfrican Crop Science Conference Proceedings, Vol. 9. pp. 399 – 406.

Baghizadeh, A., Taleei A., Naghavi, M. R. and Zeinaly, H. (2004). An evaluation of inheritance for some quantitative traits in barley using generation means analysis. *Iranian Journal of Agricultural Sciences.* 35 (4): 851-857.

Bahari, N., Bahman, B. B. and Leila, K. (2013). Evaluation of drought tolerance of bread wheat genotypes by stress and sensitivity tolerance indices. *Annals of Biological Research*, 4 (1): 43-47.

Bates, L S., Waldren, R. P. and Teare, E. D. (1973). Rapid determination of free proline for water stress studies. *Plant soil,* 39: 205-207.

Baum M., Grando S., Backes G., Jahoor A., Sabbagh A. and Ceccarelli S. (2003). QTLs for agronomic traits in the Mediterranean environment identified in recombinant inbred lines of the cross Arta *H. spontaneum* 41–1. *Theor Appl Genet.*, 107:1215–1225.

Behall, K.M., Scholfield, D.J. and Hallfrisch, J. (2004). Diets containing barley significantly reduce lipids in mildly hypercholesterolemic men and women. *American Journal of Clinical Nutrition*, 80: 1185–1193.

Bengtsson, B. O. (1992). Barley genetics. *Trends in Genetics*. 8: 3-5.

Bhatnagar, V. K., Sharma, S. N. and Sastry, E. V. D. (2002). Genetics of quantitative characters in six-rowed Barley over environments. *Indian J. Genet.*, 61 (4): 358-359.

Blum, A. (1988). Plant breeding for stress environments. CRC, Boca Raton, pp 221–223.

Bothmer, R. V., Jacobsen, N., Baden, C., Jorgensen, R. B. and Linde, L. I. (1995). An ecogeographical study of the genus Hordeum. Systematic and eco geographic studies on crop genepools, 7. IPGRI, Rome, 2nd ed., pp. 129.

Bothmer, R. V., Jacobsen, N., Jørgensen, R. B. and Linde, L. I. (1991). An ecogeographical Study of the Genus *Hordeum*. Systematic and ecogeographic studies on crop genepools 7. *International Board for Crop Genetic Resources*, Rome, Italy. pp. 112.

Braaten, J. T., Wood, P. J., Scott, F. W., Riedel, K. D., Poste, L. M. and Collins, M. W. (1991). Oat gum lowers glucose and insulin after an oral glucose dose. *American Journal of Clinical Nutrition*, 53:1425–1430.

Budak, N. (2000). Heterosis, general and specific combining ability estimates at F_1 and F_2 generations of a 8 × 8 diallel cross population of barley. *Turkish Journal of Field Crops*. 5 (2): 61-70.

Burton, G. W. and De Vance, E. H. (1953). Estimating heirtability in tall fescus (*Festuca arrundinaceae*) from replicated clonal material. *Agron. J*., 45: 478-481.

Byrne, P. F., Bolanos, J., Edmeades, G. O. and Eaton, D. L. (1995). Gains from selection under drought versus multi-location testing in related tropical maize populations. *Crop science*, 35: 63-69.

Calhoum, D. S., Gebeyehu, G., Miranda. A., Rajaram. S. and Van G. M. (1994). Choosing evaluation environments to increase whaet grain yield under drought conditions. *Crop science*, 34: 673-678.

Cavallero, A., Empilli, S., Brighenti, F. and Stanco, A. M. (2002). High beta glucan barley fractions in bread making and their effects on human glucemic response. *Journal of Cereal Science*, 36: 59–66.

Cavalli, L. (1952). An Analysis of Linkage in Quantitative Inheritance. Rieve E C R and Waddington C H (Eds). HMSO, London, pp 135–144.

Ceccarelli S., Grando, S., Baum, M. and Udupa, S.M. (2004). Breeding for drought resistance in changing climate, *in*: F.W.G. Baker (Ed.), Drought Resistance in Cereals, CAB Int., Wallingford, UK, pp. 167-190.

Ceccarelli S., Grando, S., Hamblin, J. (1992). Relationship between barley grain yields measured in low and high yielding environments. *Euphytica*, 64: 49-58.

Ceccarelli, S. and Grando, S. (1996). Drought as challenge for the plant breeder. *Plant Growth Regul*. 20: 149-155.

Ceccarelli, S. and Grando, S. (2002). Plant breeding with farmers requires testing the assumptions of conventional plant breeding: Lessons from the ICARDA barley program. In: Cleveland, David A. and Daniela. Soleri, (Eds.). Farmers, scientists and plant breeding: Integrating Knowledge and Practice. Wallingford, Oxon, UK: CAB Publishing International. pp.297–332.

Ceccarelli, S., Grando S. and Impiglia, A. (1998). Choice of selection strategy in breeding barley for stress environments. *Euphytica* 103: 307–318.

Chang, T. T., Loresto, G. C., Toole, J. C. and Armento Soto, J. L. (1982). Strategy and methodology of breeding rice for drought prone areas. International symposium. International Rice Res. Inst.; Philippines. Pp.217-244.

Chen, Z., Cuin T. A., Zhou, M., Twomey, A., Bodapati, P. N. and Sergey, S. (2007). Compatible solute accumulation and stress-mitigating effects in barley genotypes contrasting in their salt tolerance. *Journal of Experimental Botany,* 58 (15/16): 4245–4255.

Czuchajowska, Z., Klamczynski, A., Paszczynska, B. and Baik, B.K. (1998). Structure and functionality of barley starches. *Cereal Chemistry*, 75: 747–754.

Dehbalaei, S., Ezatollah F. and Farshadfar, M. (2013). Assessment of drought tolerance in bread wheat genotypes based on resistance/ tolerance indices. *International Journal of Agriculture and Crop Sciences*, 5(20): 2352-2358.

Delauney, A. J. and Verma, D. P. (1993). Proline biosynthesis and osmoregulation in plants. *Plant. J.*, 4: 215-223.

Desale, C. S. and. Mehta, D. R. (2013). Heterosis and combining ability analysis for grain yield and quali1ty traits in bread wheat (*Triticum aestivum* L.). *Electronic Journal of Plant Breeding*, 4(3): 1205-1213.

Doyle, J. J. and Doyle, J. L. (1987). A rapid DNA isolation procedure for small quantities of fresh leaf tissue. *Phytochemical Bulletin*, 19: 11-15.

El-Aty, M. S. M, Amer, K. H. A., Eldegwy, I. S. and El-Akhdar, A. A. A. (2011). Genetic studies on yield and its components in some barley crosses. *J Plant Production* 2(11): 1537 - 1550.

EL-Bawab, A. M. O. (2003). Genetic studies on some characters in barley. *Journal of Agricultural Research*, 5: 81-82.

Eshghi, R. and Akhundova, E. (2009). Genetic analysis of grain yield and some agronomic traits in hulless barley. *African Journal of Agricultural Research,* 4 (12): 1464-1474.

Eshghi, R., Ojaghi, J., Rahimi, M., Salayeva, S. (2010). Genetic characteristics of grain yield and its components in barley (*Hordeum vulgare* L.) under normal and drought conditions. *American Eurasian J Agric & Environ Sci.*, 9(5): 519-528.

Eviatar, N. and Chen, G. (2010). Drought and salt tolerances in wild relatives for wheat and barley improvement. *Plant, Cell and Environment,* 33: 670–685.

Fadel, J. G., Newman, R. K., Newman, C. W., Barnes, A. E. (1987). Hypocholesterolemic effects of b-glucans in different barley diets fed to broiler chicks. *Nutrition Reports International,* 35: 1049-1058.

FAO, (2012) FAOSTAT (Food and Agriculture Organization of the United Nations). http://faostat.fao.org/.

Farquhar, G., D. and Sharkey, T., D. (1982). Stomatal conductance and photosynthesis. *Annu. Rev. Plant. Physiol*., 33: 317-345.

Fastnaught, C. E. (2001). Barley fibre. *In*: Cho, S., Dreher, M. (Eds.), Handbook of Dietary Fibre. Marcel Dekker, New York, pp. 519–542.

Fastnaught, C. E., Berglund, P. T., Holm, E. T., Fox, G .J. (1996). Genetic and environmental variation in b-glucan content and quality parameters of barley for food. *Crop Science,* 36: 941-946.

Fellahi, Z. A., Abderrahmane H., Hamenna B. and Ammar, B. (2013). Line × Tester mating design analysis for grain yield and yield related traits in bread wheat (*Triticum aestivum* L.). *International Journal of Agronomy,* 1: 1- 9.

Fisher, R. A. and Maurer, R. (1978). Drought resistance in spring wheat cultivars. III yield associated with morpho-physiological traits. *Aus J.Agric Res.,* 30: 1001-1020.

Forster, B. P., Ellis, R. P., Moir, J., Talamè, V., Sanguineti, M. C., Tuberosa, R., This, D., Teulat,M. B., Ahmed, I., Mariy, S., Bahri, H., Muahabi, M., Zoumarou, W. N., El-fellah, M. and Salem, M. B. (2004). Genotype and phenotype associations with drought tolerance in barley tested in North Africa. *Ann Appl Biol*., 144: 157–168.

Gonzalez, A. and Ayerbe, L. (2010). Effect of terminal water stress on leaf epicuticular wax load, residual transpiration and grain yield in barley. *Euphytica*. 172 (3): 341-349.

GonzÁlez, A., Bermejo, V. and Gimeno, B. S. (2010). Effect of different physiological traits on grain yield in barley grown under irrigated and terminal water deficit conditions. *Journal of Agricultural Science*. 148 (3): 319-328.

Grando, S., Bohmer R. V., Ceccarelli S. (2001). Genetic diversity of barley: use of locally adapted germplasm to enhance yield and yield stability of barley in dry areas, *in*: H.D. Cooper, et al. (Eds.), Broadening the Genetic Base of Crop Production, CAB Int., New York/FAO, Rome/IPRI, Rome, pp. 351-372.

Guo, P., Michael, B., Grando, S., Ceccarelli, S., Guihua B., Li, R., Maria K., Varshney R K., Graner A. and Jan V. (2009). Differentially expressed genes between drought-tolerant and drought-sensitive barley genotypes in response to drought stress during the reproductive stage. Journal of Experimental Botany, Vol. 60, No. 12, pp. 3531–3544.

Gupta, S., Ahmed, Z. and Gupta, R. B. (1989). Combining ability in bread wheat. *Indian J. Genet.,* 49: 25-28.

Hanamaratti, N. G., Salimath, P. M., Mohankumar, H. D. and Shailaja, H. (2004). Genetic and physiological basis of breeding productive and drought tolerant genotypes in upland rice. In: Proc. workshop on resilient crops for water limited environments. Cuernavaca, Mexico pp100-101.

Hayman, B I. and Mather. (1955). the description of genetics interactions in continuous variation. *Biometrics*, 11: 69-82.

Hayman, B. I. (1958). The separation of epistasis from additive and dominance variation in generation means. Heredity pp.371-391.

Hayman, B. I. (1960). The separation of epistatic and dominance variation in generation means, II. *Genetics*, 31: 133-146.

Izydorczyk, M. S., Storsley, J., Labossiere, D., MacGregor, A. W., Rossnagel, B. G. (2000). Variation in total and soluble b-glucan content in hulless barley: effects of thermal, physical, and enzymic treatments. *Journal of Agricultural and Food Chemistry, 48*: 982–989.

Jain, S. K. and E. V. D. Sastry. (2012). Heterosis and combining ability for grain yield and its contributing traits in bread wheat (*Triticum aestivum* L.). Research and Reviews: *Journal of Agriculture and Allied Sciences,* 1: 1-7.

Jensen, N. P. (1970). A diallel selective mating system for cereal breeding. *Crop Science*, 10: 629–663.

Jiang, Q., Roche, D., Monaco, T. A., Hole, D. (2006). Stomatal conductance is a key parameter to assess limitations to photosynthesis and growth potential in barley genotypes. *Plant Biol* (Stuttg) 8(4): 515-521.

Jinks, J. L. and Jones, R. M. (1958). Estimation of components of heterosis. *Genetics* 43: 223-224.

Joshi, A. B. (1979). Breeding methodology for autogamous crops. *Indian J Genet*. 39: 567–578.

Kakani, R. K., Sharma, Y., Sharma, S. N. (2007). Combining ability of barley genotypes in diallel crosses. *SABARO J Breed Genet,* 39: 117-126.

Kempthorne, O. (1957). An introduction to genetic statistics. New York: John Willey & Sons.

Khan, M. A., Nadeem, A., Muhammad A., Rehman A. and Muhammad M. I. (2007). Combining ability analysis in wheat. *Pak. J. Agri. Sci.,* 44(1): 245-264.

Khokhar, M. I., Jaime, A., Teixeira, S. and Huub S. (2012). Evaluation of barley genotypes for yielding ability and drought tolerance under irrigated and water-stressed conditions. *American-Eurasian J. Agric. & Environ. Sci.,* 12 (3): 287-292.

Koumber, R. M. and El-Gammaal, A. A. (2012). Inheritance and gene action for yield and its attributes in three bread wheat crosses (*Triticum aestivum* L.). *World Journal of Agricultural Sciences*, 8(2): 156-162.

Kuczynska, A., Surma, M. and Adamski, T. (2007). Methods to predict transgressive segregation in barley and other self-pollinated crops. *J Appl Genet*, 48(4): 321–328.

Kularia, R. K. and Sharma, A. K. (2005). Generation mean analysis for yield and its component traits in barley (*Hordeum vulgare* L.). *Indian J Genet.,* 65(2): 129-130.

Kularia, R. K. and Sharma A. K. (2006). Heterobeltiosis and inbreeding depression in barley (*Hordeum vulgare* L.). *Indian J. Genet.,* 66(1): 41-42.

Kumar, V., Khippal, A., Singh, J., Selvakumar, R., Mali, R., Kumar, D., Kharub, A. S., Verma R. P. S. and Sharma, I. (2014). Barley research in India: Retrospect & Prospects. *Journal of Wheat Research,* 6(1):1-20.

Kumari, M., Singh V.P., Tripathi, R. and Joshi A.K. (2007). Variation for staygreen trait and its association with canopy temperature depression and yield traits under terminal heat stress in wheat. H.T. Buck et al. (eds.), Wheat Production in Stressed Environments, pp 357–363.

Lakewa, B., Eglintonb, J., Henryc, R. J., Baumd, M., Grando S., Ceccarelli, S. (2011). The potential contribution of wild barley (Hordeum vulgare ssp. spontaneum) germplasm to drought tolerance of cultivated barley (*H. vulgare ssp. vulgare*). *Field Crops Research*, 120: 161–168.

Lal, J. P., Singh, H,, Nandan, R. and Kumar, H. (2009). Transgressive segregants for higher productivity and drought tolerance under water limited environments in barly (Hordeum vulgare L.) Paper presented in an International Conference on Interdrought-III (3rd International Conference on Integrated Approaches to Improve Crop Production under Drought Prone Conditions) held at Shanghai, China between Oct. 11 to 16, 2009.

Lal, J. P., Singh, H., Nandan, R., Prasad, L. C. and Kumar, H. (2011). Recombinants for enhanced productivity and drought tolerance in barley (*Hordeum vulgare* L.). *Journal of Agricultural Science and Technology* 1: 550-555.

Li, C., Zhang, G. and Lancerecent, R. (2007). Advances in breeding barley for drought and saline stress tolerance. *In*: M.A. Jenks et al. (eds.), *Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops*, pp 603–626.

Li, R., Guo P., Baum, M., Grando S. and Ceccarelli S. (2006). Evaluation of chlorophyll content and fluorescence parameters as indicators of drought tolerance in barley. *Agricultural Sciences in China*, 5(10): 751-757.

Liu, Z. W., Biyashev, R. M, Saghai, M. M. A. (1996). Development of simple sequence repeat DNA markers and their integration into a barley linkage map. *Theor Appl Genet*, 93: 869-876.

Lush, J. L. (1949). Heritability of quantitative traits in farm animals, Proc. 8th Int. Cong. Genetika, Heridas (supp), 336-357.

Madic, M, R., Dragan, S. D., Desimir, S. K., Aleksandar, S. P. and Snezana, T. T. (2014). Combining abilities for spike traits in a diallel cross of barley. *Journal of Central European Agriculture,* 15(1): 108-116.

Madic, M., Knezevic, D., Paunovic, A., Djuric, M., Veljkovic, B. and Djurovic, D. (2007). Combining abilities for grain weight per plant in two-rowed barley hybrids. *Acta Agriculturae Serbica*. 12 (24): 3-11.

Majid, M., Ali, A. and Essia, B. (2012). Effect of salinity on sodium and chloride uptake, proline and soluble carbohydrate contents in three alfalfa varieties. *IOSR Journal of Agriculture and Veterinary Science,* 1(6): 01-06.

Marconi, E., Graziano, M. and Cubadda, R. (2000). Composition and utilization of barley pearling by-products for making functional pasta rich in dietary fibre and b-glucans. *Cereal Chemistry*, 77: 133-139.

Marlett, J. (1991). Dietary fibre content and effect of processing on two barley varieties. *Cereal Foods World*, 36: 576-578.

Mather, K. (1949). Biometrical Genetics-The Study of Continuous Variation, Methuen and Co Ltd, London pp-192.

Mather, K. and Jinks, J. L. (1977). *Introduction to Biometrical Genetics*. Ithaca, New York: Cornell University Press pp.23.

Mather, K. and Jinks, J. L. (1982). Biometrical Genetics, 3rd edn. Chapman and Hall Ltd, London. pp-254.

Morgan, J. M. (1984). Osmoregulation and water stress in higher plants. *Ann Rev Plant Physiol*., 35: 299–319.

Pal, D. and Kumar, S. (2009). Genetic analysis of forage yield and other traits in barley (*Hordeum vulgare* L.). *Barley Genetics Newletter*, 39: 13-19.

Pathak, R. S. and singh, R. B. (1970). Genetics of yield and characters in upland cotton. *Indian J. Gent. Breed.* 30: 679-689.

Pawar, K. K. and Singh, A. K. (2013). Combining ability analysis for grain yield and its attributing traits in barley. *Int. J. Agric.Sc & Vet.Med*, 2: 45-48.

Pins, J. J., Kaur, H. (2006). A review of the effects of barley b-glucan on cardiovascular and diabetic risk. *Cereal Foods World*, 5:8-11.

Poehlman, J. M. (1987). Breeding field crops, AVI Pub. Co. Inc. West port Connecticut p. 378-420.

Potla K. R., Bornare, S. S., Prasad, L. C., Prasad R. and Madakemohekar A. H (2013). Study of heterosis and combining ability for yield and yield contributing traits in barley (*Hordeum vulgare* L.) 8(4): 1231-1235.

Quinde, Z., Ullrich, S. E. and Baik, B. K. (2004). Genotypic variation in colour and discolouration potential of barley-based food products. *Cereal Chemistry*, 81: 752–758.

Qureshi, A. A., Burger, W. C., Peterson, D. M. and Elson, C. E. (1986). The structure of an inhibitor of cholesterol biosynthesis isolated from barley. *Journal of Biological Chemistry*, 261: 10544-10550.

Qureshi, A. A., Qureshi, N., Wright, J. J. K., Shen, Z., Kramer, G., Gapor, A., Chong, Y. H., Dewitt, G., Ong, A. S. H., Peterson D. M. and Bradlow, B. A. (1991). Lowering serum cholesterol in hypercholesterolemic humans by tocotrienols (palmvitee). *American Journal of Clinical Nutrition*, 53: 1021-1026.

Rabbani, G., Muhammad, M., Ajmal S. U. K., Hassan F., Shabbir, G. and Abid, M. (2009). Inheritance of yield attributes in bread wheat under irrigated and rainfed conditions. *Sarhad J. Agric*., 25(3): 25-35.

Rad, M. R. N., Mihdzar A. K., Rafii M. Y., Hawa Z. E. and Mahmoud D. (2013). Gene action for physiological parameters and use of relative water content (RWC) for selection of tolerant and high yield genotypes in F_2 population of wheat. *Australian Journal of Crop Science*, 7(3): 407-413.

Raikwar, R. S, Upadhyay, A. K., Gautam, U. S., Singh, V. K. (2014). Genetic architecture of quantitative traits in barley (*Hordeum vulgare* L.). *Indian J Genet.* 74(1): 93-97.

Raikwar, R. S. (2013).The nature and magnitude of gene effects for yield and its quality traits in barley (*Hordeum vulgare* L.) under saline sodic soil. *Scholarly Journal of Agricultural Science*, 3(5): 154-166.

Ramsay, L., Macaulay, M., Degli, I. S., MacLean, K., Cardle. L, Fuller, J., Edwards, K. J., Tuvesson, S., Morgante, M., Massari, A., Maestri, E., Marmiroli, N., Sjakste, T., Ganal, M., Powell, W. and Waugh, R. (2000). A Simple Sequence Repeat based linkage map of barley. *Genetics,* 156: 1997–2005.

Robredo, A., Lopez, U. P., Mazaa, H. S., Gonzalez, M. B., Lacuesta, M., Mena-Petite, A. and Munoz Rueda, A. (2007). Elevated CO2 alleviates the impact of drought on barley improving water status by lowering stomatal conductance and delaying its effects on photosynthesis. *Environmental and Experimental Botany*, 59: 252–263.

Rugen, X, Lu, C., Li Z., Meixue Z., Mo Huidong, Z, and Wu, X. B. (2004). Studies on heterosis of barley (*Hordeum vulgare* L). *J.Acta. Agronomica Sinica,* 30(7): 668-674.

Saad, F. F., Abd El, M., Abd El, M. A. S. and Al-Soudan, I. H. (2013). Genetic behaviour of grain yield and its components in barley crosses under water stress and non -stress conditions. *Sci. Agri.*, 1(2): 45-55.

Saini, D. D. and Prakash, V. (2005). Heterotic performance for yield and yield traits in duram wheat crosses. *Crop improve*, 20:130-136.

Salgotra, R. K., Thakur, K. S., Sethi, G. S. and Sharma, J. K. (2002). Heterosis in winter x spring wheat crosses. *Indain J Genet*., 62: 104-106.

Samarah, N H. (2005). Effects of drought stress on growth and yield of barley. *Agron. Sustain. Dev.,* 25: 145–149.

Schneider, K. A., Rosales S. R., Ibarra, P. F., Cazarews, E. B, Acosta, G. J. A., Ramirez, V. P., Wassimi, N. and Kelly, J. D. (1997). Improving common bean performance under drought stress. *Crop science*, 37: 43-50.

Serraj, R. and Sinclair, T. R. (2002). Osmolyte accumulation: can it really help increase crop yield under drought conditions. *Plants Cell Environ*., 25: 333-341.

Sethi, G. S. and Singh, H. B. (1974). Relationship between yield and yield contributing characters in triple dwarf wheat. *Indian J. Genet*., 44: 585-590.

Sharma, A., Kapur, P. and Katoch, V. (2012.) Generation mean analysis to estimate genetic parameters for desirable horticultural traits in garden pea (*Pisum sativum*) *Indian Journal of Agricultural Sciences*, 82 (3): 201–206.

Sharma, S. N. and Sain, R. S. (2002). Inheritence of tillers for plant in durum wheat (*Triticum durum* Desf). *Indian J Genet.*, 62 (2): 101–103.

Sharma, Y., Sharma, S. N., Joshi P. and Sain R. S. (2002). Combining ability analysis for yield and yield contributing characters in six-rowed barley. *SABRAO Journal of Breeding and Genetics*, 34(2): 55-63.

Sharma, Y., Sharma, S.N. and Joshi A. (2003). Genetic analysis of yield and its component traits in barley. *Indian Journal of Plant Genetic Resources*, 16(2): 138-142.

Sinclair, T. R. (2000). Model analysis of plants traits leading to prolonged survival during severe drought. *Field Crop Res.*, 68: 211-217.

Singh H. C., Singh S. and Singh, S.K. (2011). Combining ability and heterosis in six rowed barley. *Indian Journal of Plant Genetic Resources*, 16(2): 90-98.

Singh, H., Sharma, S. N. and Sain, R. S. (2004). Heterosis studies for yield and its components in bread wheat over environments. *Hereditas*, 141: 106–114.

Singh, P., Bhadauria, A, and Singh, P. K. (2008). Combining ability and gene action for Alternaria blight and powdery mildew resistance in linseed. *Indian J Genet.*, 68 (1): 65–70.

Singh, S., Dhindsa, G. S., Sharma, A. and Singh, P. (2007). Combining ability for grain yield and its components in barley {hordeum vulgare l.). *Crop Improvement*,34 (2): 128-132.

Singh, T. N., Aspinall, D. and Paleg, L. G. (1972). Proline accumulation and varietal adaptability to drought in barley: a potential metabolic measure of drought resistance, *Nature New Biology*, 236: 188-190.

Singh, V., Ram Krishna, Singh, S. and Prashant, V. (2012). Combining ability and heterosis analysis for yield traits in bread wheat (Triticum aestivum). *Indian Journal of Agricultural Sciences*, 82 (11): 916–921.

Teulat, B., Merah, O., Souyris, I. and This, D. (2001). QTLs for agronomic traits from a Mediterranean barley progeny grown in several environments. *Theor Appl Genet*, 103: 774–787.

Thiel, T., Michalek, W., Varshney R. K., Graner A. (2003). Exploiting EST databases for the development and characterization of gene-derived SSR-markers in barley (*Hordeum vulgare* L.) *Theor Appl Genet*, 106: 411–422.

Ueda, A., Weiming, S., Kazutsuka, S., Mariko S. and Tetsuko T. (2001). Functional analysis of salt inducible proline transporter of barley roots. *Plant cell physiology*, 42(11): 1282-1289.

Vaezi, B., Bavei, V. and Shiran, B. (2010). Screening of barley genotypes for drought tolerance by agro-physiological traits in field condition. *African Journal of Agricultural Research.* 5 (9): 881-892.

Varzaru, S. and Ciulca S. (2013). Analysis of gene effects for grains traits in winter barley. *Journal of Horticulture, Forestry and Biotechnology*, 17(2): 299- 302.

Ved Prakash and Verma, R. P. S. (2006). Inheritance of grain yield and some quantitative traits in six rowed barley (*Hordeum vulgare* L.). *Indian Journal of Genetics and Plant Breeding*, 66 (1): 39-40.

Verma, R. P. S., Kharub, A. S., Kumar, D., Sarkar, B., Selvakumar, R., Singh, R., Malik, R., Kumar R. and Sharma, I. (2010). Fifty years of coordinated barley research in India. Directorate of Wheat Research, Karnal-132001. *Research Bulletin* No. 27: 46.

Verma, A. K., Vishwakarma, S. R. and Singh, P. K. (2007). Line x tester analysis in barley (*Hordeum vulgare* L.) across environments. *Barley Genetics Newsletter*, 37: 29–33.

Virkki, L., Johansson, L., Ylinen, M., Maunu, S. and Ekholm, P. (2004). Structural characterization of water-insoluble non-starchy polysaccharides of oats and barley. *Carbohydrate Polymers*, 59: 357–366.

Wood, P. J., Braaten, J. T., Scott, F. W., Riedel, D. and Poste, L. M., (1990). Comparisons of viscous properties of oat and guar gum and the effects of these and oat bran on glycemic index. *Journal of Agricultural and Food Chemistry*, 38: 753-757.

Yadav, V. K., Ram, L., Kumar, R., Singh, S. P. (2002). Genetics of yield components and some making attributes in barley (*Hordeum vulgare* L.). *Progressive Agriculture*, 2(1): 1-18.

Yawen, Z. and Chen, L. (2001). Combining ability and heterosis in forage barley. *Indian J. Genet.*, 61(1): 71-73.

Yılmaz, R. and Konak, C. (2000). Heterotic effects regarding salt tolerance in some characters of barley. *Turkish Journal of Agriculture & Forestry*, 24 (6): 643-648.

Zhu, J. K., Hasegawa P. M. and Bressan R. A. (1997). Molecular aspects of osmotic stress in plants. *Crit Rev Plant Sci.*, 16: 253–277.

APPENDICES

Appendix I: Monthly meteorological data during crop growth period from December 2011 to April 2012.

Month	Temperature (˚C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum		
December	22.27	9.75	94.00	54.75	4.85	0.00
January	21.04	10.2	88.20	54.40	5.76	2.60
February	26.35	11.6	80.00	43.00	8.95	0.00
March	31.87	15.82	69.00	38.75	8.77	1.60
April	38.36	22.16	54.60	21.60	9.56	2.30

Appendix II: Monthly meteorological data during crop growth period from December 2012 to April 2013.

Month	Temperature (˚C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum		
December	22.07	10.40	84.25	48.25	5.40	0.00
January	21.24	8.06	87.20	46.40	5.72	0.00
February	24.45	12.55	87.75	55.25	7.22	3.10
March	32.05	17.27	69.00	35.00	8.92	2.40
April	37.02	21.55	55.75	28.50	8.95	2.60

Appendix III: Mean table of lines and testers and crosses for thirteen quantitative traits under moisture stress (rainfed) condition during *rabi* 2011-12.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	81.33	112.33	69.92	12.60	6.47	12.03	30.31	51.12	56.23	12.38	42.77	1283.33	2.53
BCU 4922	78.67	111.67	59.80	13.17	8.87	13.83	19.42	44.56	57.63	9.45	43.63	1333.33	2.46
BCU 4925	78.67	110.67	61.12	11.90	5.30	13.83	16.38	47.13	69.07	11.13	50.00	1496.67	2.22
BCU 4927	77.33	111.00	59.63	11.60	8.23	13.67	22.48	40.92	54.67	10.17	48.97	1254.00	2.46
BCU 4932	78.33	111.33	61.88	16.67	9.50	13.67	25.34	46.42	63.57	14.55	45.23	1348.67	2.33
BCU 4956	77.67	108.00	64.33	13.20	9.70	10.53	25.33	32.85	79.33	5.91	46.20	1213.00	2.91
Testers													
Lakhan	74.00	107.33	80.79	9.93	7.10	12.73	35.79	44.28	61.63	14.43	39.00	1270.00	2.95
Karan 16	76.33	108.33	68.98	9.87	6.83	11.70	38.34	45.33	63.87	15.77	50.90	1316.67	2.55
RD 2035	75.33	108.33	70.52	10.50	7.43	11.37	34.42	35.72	63.67	14.95	41.77	1236.67	2.07
K 603	79.33	109.67	86.42	10.60	7.63	14.43	48.22	39.17	57.33	13.33	40.13	1250.00	2.41

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	82.00	114.00	74.59	15.23	8.13	15.33	25.80	62.71	80.13	14.13	52.60	1353.33	2.40
BCU 4910 x Karan 16	83.33	116.00	71.67	18.20	10.03	15.63	26.78	57.95	75.27	19.00	52.47	1288.00	2.56
BCU 4910 x RD 2035	84.33	115.67	73.33	15.77	7.00	16.23	16.49	71.70	87.00	18.40	53.97	1235.00	2.72
BCU 4910 x K 603	83.67	117.00	74.00	15.60	8.43	17.63	27.33	53.67	65.43	15.50	47.73	1326.67	2.32
BCU 4922 x Lakhan	84.00	114.67	87.25	19.03	10.30	17.43	34.74	63.97	60.80	29.67	48.17	1286.67	2.61
BCU 4922 x Karan 16	85.00	117.33	69.82	13.17	7.73	16.17	24.35	44.33	74.33	12.96	40.00	1276.67	2.47
BCU 4922 x RD-2035	82.67	114.33	76.50	16.47	9.33	16.57	30.37	58.53	58.67	16.53	50.33	1370.00	2.37
BCU 4922 x K-603	82.00	114.33	77.74	18.00	9.67	16.87	25.84	59.37	73.03	17.22	45.57	1335.00	2.71
BCU 4925 x Lakhan	84.00	115.00	76.23	18.63	10.52	17.37	31.38	63.22	69.77	23.07	49.30	1300.00	2.45
BCU 4925 x Karan 16	84.33	118.67	63.67	18.87	8.70	15.23	27.15	54.91	80.10	25.67	50.03	1206.67	2.85
BCU 4925 x RD 2035	86.33	118.67	71.05	18.57	8.43	16.63	24.38	69.68	83.27	28.88	50.93	1140.00	2.63
BCU 4925 x K 603	81.33	113.67	72.46	14.60	7.83	13.27	21.50	56.18	69.67	12.82	50.17	1360.00	2.39
BCU 4927 x Lakhan	84.33	118.00	72.15	13.03	8.23	15.50	21.04	69.94	58.77	21.45	48.97	1157.33	2.89
BCU 4927 x Karan 16	85.67	115.33	71.22	19.44	9.80	14.98	25.26	56.29	71.87	28.72	47.43	1313.33	2.59
BCU 4927 x RD 2035	85.00	119.33	77.96	14.03	10.50	14.47	30.03	65.12	75.47	22.33	45.70	1313.33	2.79
BCU 4927 x K 603	85.00	119.00	74.83	13.87	9.50	13.63	22.61	64.96	69.47	19.59	53.73	1190.00	2.46
BCU 4932 x Lakhan	81.33	114.00	72.74	16.33	10.00	16.57	21.51	62.28	86.77	21.21	53.57	1293.33	2.42
BCU 4932 x Karan 16	85.67	117.67	65.03	17.43	8.57	18.10	28.33	52.50	58.80	16.00	48.90	1310.00	2.29
BCU 4932 x RD 2035	83.00	116.33	68.80	17.67	9.13	16.90	28.33	50.63	79.50	16.40	46.90	1343.33	2.32
BCU 4932 x K 603	82.00	114.67	65.94	15.43	7.10	13.60	22.38	48.35	83.33	16.50	42.20	1283.33	2.82
BCU 4956 x Lakhan	81.33	114.33	75.03	19.23	10.27	17.33	26.36	66.47	85.00	19.70	44.23	1216.67	2.75
BCU 4956 x Karan 16	83.67	116.67	71.46	16.60	9.50	12.90	25.61	52.91	67.00	16.67	45.00	1186.67	2.53
BCU 4956 x RD 2035	81.67	114.00	73.11	17.40	9.70	16.02	24.56	62.90	81.70	20.05	46.43	1316.67	2.78
BCU 4956 x K 603	82.00	117.67	79.07	17.60	10.43	15.33	25.20	64.12	84.70	20.87	45.83	1282.33	2.24

Appendix IV: Mean table of lines and testers and crosses for thirteen quantitative traits under moisture (irrigated) condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	81.33	112.67	85.95	7.70	7.72	13.46	23.79	51.12	57.33	10.53	37.83	1463.33	1.19
BCU 4922	81.00	113.00	85.07	8.20	10.01	12.47	26.87	46.66	53.52	9.71	45.10	1463.33	1.32
BCU 4925	78.17	110.33	80.47	11.93	7.61	14.05	24.27	50.46	54.20	10.89	46.00	1560.00	1.41
BCU 4927	76.87	109.33	83.17	11.13	7.03	13.50	23.63	47.63	54.32	11.16	46.83	1409.00	1.48
BCU 4932	76.67	108.33	83.57	11.07	8.38	13.20	26.13	47.51	53.70	11.62	42.90	1378.67	1.21
BCU 4956	75.67	109.33	75.80	10.09	9.15	14.66	27.03	48.85	60.56	11.14	41.77	1480.00	1.46
Testers													
Lakhan	78.00	111.33	82.73	9.21	8.29	14.94	59.54	45.31	60.26	16.47	40.63	1350.00	1.48
Karan 16	78.33	110.67	71.20	8.07	6.15	11.92	45.39	38.47	63.90	12.31	45.85	1426.67	1.65
RD 2035	77.00	110.33	68.40	7.74	6.99	12.48	44.33	38.35	53.49	10.49	38.40	1467.67	1.30
K 603	77.00	110.00	82.87	8.45	8.49	12.51	45.07	45.87	55.91	13.75	37.37	1385.33	1.48

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	82.67	114.67	86.47	11.10	8.91	15.23	26.90	52.35	59.60	12.48	43.07	1410.00	1.85
BCU 4910 x Karan 16	81.67	113.33	88.00	12.88	9.13	16.97	24.05	58.77	63.11	13.67	39.43	1570.33	1.50
BCU 4910 x RD 2035	82.43	113.67	87.07	15.34	8.65	16.11	24.07	56.64	59.60	18.13	36.67	1471.33	1.63
BCU 4910 x K 603	85.33	117.33	92.90	16.75	8.75	16.52	26.40	60.04	64.76	17.07	41.45	1476.33	1.29
BCU 4922 x Lakhan	84.33	116.00	106.57	19.35	8.55	16.40	26.40	60.00	60.88	18.43	41.50	1560.00	1.28
BCU 4922 x Karan 16	84.67	114.00	85.49	18.04	9.14	14.97	26.08	54.37	64.97	17.21	44.47	1553.00	1.48
BCU 4922 x RD-2035	80.67	113.33	73.20	11.57	7.72	15.02	28.00	45.39	60.89	13.49	40.27	1395.00	1.53
BCU 4922 x K-603	83.27	117.00	82.97	12.67	9.64	14.95	24.90	46.49	54.88	13.66	44.27	1433.33	1.32
BCU 4925 x Lakhan	84.03	116.33	96.10	16.60	9.75	16.90	24.60	64.35	60.97	19.46	40.77	1446.67	1.41
BCU 4925 x Karan 16	82.67	113.33	82.73	12.20	8.51	15.00	28.17	51.90	56.34	11.53	49.27	1468.67	1.63
BCU 4925 x RD 2035	82.83	112.00	84.97	14.77	9.88	14.42	27.67	53.87	57.43	12.45	48.00	1490.00	1.44
BCU 4925 x K 603	82.00	114.00	91.63	16.30	8.52	15.41	24.43	61.89	59.23	20.03	43.63	1460.00	1.53
BCU 4927 x Lakhan	83.00	115.00	97.37	16.43	8.74	17.50	26.43	57.26	58.14	18.94	41.10	1497.67	1.75
BCU 4927 x Karan 16	80.33	114.00	82.43	16.27	8.83	17.01	27.87	54.57	62.87	17.88	41.97	1413.33	1.51
BCU 4927 x RD 2035	81.67	115.67	81.27	15.67	8.11	16.15	22.50	55.51	59.31	15.78	43.30	1589.67	1.37
BCU 4927 x K 603	85.00	119.00	91.84	14.92	10.05	17.03	26.73	58.77	60.17	18.29	44.40	1353.00	1.56
BCU 4932 x Lakhan	86.67	119.67	96.20	20.57	9.80	17.47	25.90	58.94	61.74	23.31	39.23	1460.67	1.66
BCU 4932 x Karan 16	83.33	116.33	79.11	10.60	8.32	16.02	26.80	48.15	62.97	15.70	40.53	1520.33	1.41
BCU 4932 x RD 2035	84.00	115.33	83.87	13.06	9.19	16.35	24.67	47.73	58.88	13.01	47.93	1503.33	1.58
BCU 4932 x K 603	85.33	118.33	92.80	18.99	11.35	18.50	26.60	63.70	55.65	18.49	44.87	1430.00	1.58
BCU 4956 x Lakhan	82.33	115.00	86.60	18.53	8.27	16.37	26.17	67.41	62.06	18.38	49.83	1415.33	1.59
BCU 4956 x Karan 16	81.00	113.00	86.22	17.72	8.69	15.61	28.17	63.34	57.29	19.37	50.27	1560.00	1.37
BCU 4956 x RD 2035	77.33	109.67	75.50	11.53	8.80	16.03	26.73	57.60	54.91	14.16	43.30	1450.00	1.27
BCU 4956 x K 603	78.33	111.33	87.67	20.84	8.71	13.91	26.67	63.35	63.12	15.42	51.67	1461.67	1.42

Appendix V: Mean table of lines and testers and crosses for thirteen quantitative traits under moisture stress (rainfed) condition during *rabi* 2012-13.

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
Lines													
BCU 4910	80.00	113.00	60.67	8.29	8.01	13.22	21.57	55.90	53.17	8.86	35.63	1256.67	2.33
BCU 4922	75.33	109.67	52.97	6.75	7.49	12.39	24.00	50.97	55.35	6.46	34.10	1340.00	2.37
BCU 4925	74.00	107.67	49.47	9.23	7.17	12.45	16.60	51.80	49.97	5.65	36.60	1336.67	2.50
BCU 4927	74.33	108.67	52.60	8.07	6.65	13.33	23.13	55.70	52.84	5.60	39.03	1276.67	2.21
BCU 4932	74.00	107.33	55.60	7.60	7.93	14.49	24.03	54.01	49.66	6.41	35.73	1303.33	2.49
BCU 4956	75.33	109.33	57.07	7.39	7.75	13.95	24.63	51.00	57.41	8.87	35.23	1286.67	2.76
Testers													
Lakhan	76.67	109.67	62.97	8.24	7.07	14.21	50.63	54.19	53.31	9.10	37.67	1283.33	2.75
Karan 16	75.87	108.33	56.40	6.35	6.03	11.85	42.70	45.17	53.49	7.24	36.03	1310.00	2.39
RD 2035	75.33	107.67	57.83	6.75	7.13	12.51	54.93	45.37	53.19	7.19	37.30	1311.67	2.17
K 603	75.33	108.33	71.67	6.63	7.47	12.97	52.17	51.13	53.85	8.54	40.63	1233.33	2.41

	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers	Spike length (cm)	Awn length (cm)	Number of grains per spike	Thousand grain weight (g)	Harvest index	Grain yield per plant (g)	Chlorophyll content	Stomatal conductance (m mol/m^2/s)	Proline content (mg/g)
BCU 4910 x Lakhan	83.33	116.33	78.20	17.32	8.94	16.07	26.07	57.93	52.76	14.77	39.40	1236.67	2.83
BCU 4910 x Karan 16	81.00	114.00	69.53	12.25	8.39	15.75	22.27	60.03	51.47	9.32	40.57	1210.00	2.44
BCU 4910 x RD 2035	83.00	115.67	68.40	11.05	8.21	13.71	24.27	51.03	57.45	9.49	44.60	1356.67	2.38
BCU 4910 x K 603	84.33	117.67	76.47	16.17	8.67	16.37	22.80	56.87	59.71	16.44	43.53	1323.33	2.53
BCU 4922 x Lakhan	88.67	121.67	75.67	20.57	8.75	18.93	21.60	55.00	62.51	19.58	42.47	1153.33	2.67
BCU 4922 x Karan 16	81.00	113.33	72.67	12.52	10.53	14.53	23.33	50.07	51.67	9.32	46.33	1366.67	2.31
BCU 4922 x RD-2035	83.00	116.33	72.87	9.22	8.94	12.43	23.07	48.42	54.97	8.40	44.23	1286.67	2.26
BCU 4922 x K-603	86.33	119.33	69.93	13.50	8.76	15.40	25.13	53.30	55.19	13.52	42.57	1227.33	2.58
BCU 4925 x Lakhan	84.00	117.00	72.87	14.73	8.48	17.20	24.27	55.40	52.83	14.57	43.57	1160.67	3.28
BCU 4925 x Karan 16	82.67	116.00	74.33	9.60	10.74	12.17	25.33	49.67	54.00	9.66	47.00	1350.00	2.27
BCU 4925 x RD 2035	85.67	118.67	71.87	8.65	6.91	14.31	22.87	51.83	57.83	9.13	42.20	1350.00	2.56
BCU 4925 x K 603	88.67	121.67	75.33	16.80	7.55	15.65	20.20	60.43	66.12	18.42	46.60	1316.67	2.49
BCU 4927 x Lakhan	83.67	118.33	77.93	10.80	8.23	17.05	20.93	55.23	54.97	9.53	40.57	1346.67	2.43
BCU 4927 x Karan 16	81.67	115.00	69.40	13.00	8.12	16.47	23.33	56.97	60.07	13.22	40.40	1356.67	2.15
BCU 4927 x RD 2035	83.67	116.33	72.87	14.80	8.60	15.64	24.27	53.07	52.83	14.57	44.27	1294.00	2.94
BCU 4927 x K 603	88.67	121.67	73.67	13.81	7.55	16.41	20.20	60.53	67.14	15.00	44.13	1210.00	2.52
BCU 4932 x Lakhan	84.00	119.00	65.73	15.22	8.34	19.01	20.80	64.00	60.08	17.87	39.97	1168.33	3.07
BCU 4932 x Karan 16	77.67	112.67	52.00	9.44	9.20	12.77	24.33	52.00	51.00	9.00	42.00	1275.00	2.42
BCU 4932 x RD 2035	79.33	113.67	70.33	7.05	8.11	15.09	26.67	46.57	57.03	6.65	41.33	1293.33	2.36
BCU 4932 x K 603	85.00	119.67	80.87	13.08	9.14	16.13	23.53	59.47	61.69	17.16	47.03	1251.67	2.79
BCU 4956 x Lakhan	83.67	116.67	67.60	13.83	6.53	15.92	16.53	62.50	61.53	12.07	40.77	1303.33	2.67
BCU 4956 x Karan 16	80.33	115.00	76.00	15.05	7.80	15.87	20.53	58.23	62.22	13.19	44.57	1253.33	2.17
BCU 4956 x RD 2035	85.67	118.67	65.87	9.67	7.29	14.50	18.73	60.07	60.45	9.26	43.13	1260.00	2.55
BCU 4956 x K 603	81.67	116.67	66.73	15.38	7.79	17.45	18.80	63.80	52.75	13.28	42.40	1203.33	2.71