ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF LIFE SCIENCE

Evaluation of Chickpea (*Cicer arietinum* L.) Genotypes for Genetic Parameters and Drought Tolerance



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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Biology (Applied Genetics)

By
Hussein Ahmed

March 2011

Addis Ababa

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List of abbreviations

BY	Biological yield
DII	Drought intensity index
DSI	Drought susceptibility index
DTF	Days to 50% flowering
DTI	Drought tolerance index
DTM	Days to 90% maturity
DZARC	Debre Zeit Agricultural Research Center
ECV	Environmental coefficient of variation
GCV	Genotypic coefficient of variation
GMP	Geometric mean productivity
HARM	Harmonic mean
HI	Harvest index
HSW	100 seeds weight
ICRISAT	International Crops Research Institute for the Semi Arid Tropic
MP	Mean productivity
NP	Number of pods
NPB	Number of primary branches
NS	Number of seeds
NSB	Number of secondary branches
NSPP	Number of seeds per pod
PCA	Principal Component Analysis
PCV	Phenotypic coefficient of variation
PH	Plant height
SY	Seed yield
TOL	Tolerance index
Yp	Yield under non-stress condition
Ys	Yield under stress condition

Abstract

Chickpea (*Cicer arietinum* L.) is one of the important cool season food legumes. Chickpea production is affected by various abiotic and biotic constrains which penalize seed yields. Among them, drought is known to cause substantial reduction in the seed yield of the crop. This study was conducted to evaluate chickpea genotypes for genetic parameters and drought tolerance. A total of 18 test chickpea genotypes (9 kabuli and 9 desi) together with four checks (2 kabuli and 2 desi) were studied under moisture stress and non-stress conditions in pot experiments at Debre Zeit Agricultural Research Center during 2009/2010. A randomized complete block design with three replications was used. Analysis of variance revealed significant genetic variation among the genotypes for almost all the measured traits. Mean comparisons showed that genotype ICC-16798 produced higher seed yield under moisture stress and non-stress. Genotypic and phenotypic variances were high for biological yield followed by days to 50% flowering in both water levels. However, the maximum genotypic coefficient of variation was obtained for number of seeds and number of pods per plant under moisture stress and non-stress conditions. Similarly, high phenotypic coefficient of variation was observed for seed yield followed by number of seed and number of pods per plant in both conditions. Broad sense heritability estimates ranged from medium to high. High heritability was recorded for 100 seed weight and days to 50% flowering. High heritability, coupled with high genetic advance values, was also observed for 100 seed weight and days to 50% flowering in both conditions. Moreover, there were significant positive correlation between seed yield with number of pods per plant, number of seeds per plant, harvest index and biological yield. It was also found that the correlations between seed yield with number of days to 50% flowering and days to 90% maturity were negative and significant. Phenotypic path coefficient analysis revealed that harvest index and biological yield had high positive direct effect on seed yield under both moisture stress and non-stress conditions. Similarly, multiple linear regression analysis showed that biological yield and harvest index have contributed significantly towards seed yield in non-stress condition. In stress condition, number of secondary branches, number of pods per plant, biological yield and harvest index have contributed significantly towards seed yield. Multiple statistical analyses showed that considerable influences of harvest index and biological yield were common to both conditions. Therefore, selection pressure should be directed towards these traits to improve the seed yield stability across different water levels. Based on the yields of genotypes under moisture non-stress (Y_P) and stress (Y_S) conditions, several quantitative drought tolerance indices, mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), harmonic mean (HARM), drought susceptibility index (DSI) and drought tolerance index (DTI) were used to evaluate drought responses of these genotypes. They showed that correlation coefficients of seed yield with geometric mean productivity, drought tolerance index and harmonic mean indices in both conditions were high and positively significant. These revealed that selection could be conducted for high values of GMP, DTI and HARM under both conditions for chickpea breeding programs to introduce high yielding and drought tolerant genotypes. According to the indices and biplot analysis, it is concluded that ICC-16798, ICCRIL-04-0258, ICC-11198, ICC-2072, ICCRIL-03-0208 and ICCRIL-03-0177 genotypes were superior under both conditions.

Key words/phrases: Chickpea, drought tolerance indices, heritability, path analysis

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important cool season food legume. Among the annual seed crops, it ranks 14th in terms of area and 16th in production (Knights *et al*., 2007). According to FAO (2009), it is produced on 11 million ha with annual production of 9.7 million tones worldwide. However, among the pulse crops, chickpea has consistently maintained a much more significant status, ranking second in area (15.3% of total) and third in production (14.6%) after dry beans (*Phaseolus vulgaris* L.) and dry peas (*Pisum sativum* L.) (Knights *et al*., 2007).

There are two types of chickpea: the desi type (mostly brown seeded), traditionally grown in warmer climates of Asia and Africa, mostly in India, Pakistan, Bangladesh, Myanmar and Ethiopia; and the kabuli type (white-seeded), a large-seeded variety more suited to the temperate climates of Turkey, Mexico, the USA, Afghanistan and Iran. Some countries like Canada and Australia produce both desi and kabuli types (Reddy *et al*., 2007). Kabuli type constitutes ~15% of global chickpea production and desi type constitutes the remaining 85% (Singh and Malhotra, 1984).

Chickpea is a good source of energy, protein, minerals (especially potassium, phosphorus, calcium, magnesium, copper, iron and zinc), vitamins (especially B vitamins), fibre and also contains potentially health-beneficial phytochemicals (Wood and Grusak, 2007). The protein concentration of chickpea seed ranges from 16.7% to 30.6% for desi type and 12.6% to 29.0% for kabuli type, and is commonly 2–3 times higher than that of cereal grains (Wood and Grusak, 2007). Therefore, chickpea is an inexpensive, high-quality source of protein (Yadav *et al*., 2007). Chickpea exhibits higher lipid content than other pulses. The total lipid concentration of desi and kabuli types ranges from 2.9% to 7.4% and 3.4% to 8.8%, respectively. Carbohydrates are the major nutritional component in chickpea, with 51– 65% in desi type and 54 – 71% in kabuli type (Wood and Grusak, 2007). Since chickpea is high in fibre, low in sodium and fat, and also cholesterol free, it is a healthy food that is beneficial to the prevention of coronary and cardiovascular diseases (Yadav *et al*., 2007). According to these authors, it may also lower blood cholesterol levels due to high content of soluble fibre

and vegetable protein. In addition, its residue is used as animal feed (Legesse Dadi *et al*., 2005). Chickpea is not only an important source of protein in human diets, but it also plays a significant role in maintaining soil fertility, through biological nitrogen fixation (Kantar *et al*., 2007).

Over 50 countries grow chickpea; however, India, Turkey, Pakistan, Iran, Myanmar, Mexico, and Ethiopia together contribute 93.1% of the global chickpea production. Although North and Central America and Oceania together contribute only 6.2% of the world chickpea production, these regions have the highest recorded chickpea productivity (1.09 t ha^{-1} to 1.34 t ha^{-1}). In contrast, Asia and Africa show the lowest productivity (0.75 t ha^{-1} to 0.79 t ha^{-1}) while contributing large amount of the world chickpea production (Upadhyaya *et al*., 2008).

Chickpea is one of the major pulse crops in Ethiopia and in terms of production it is the second most important legume crop after faba beans. It contributed about 16% of the total pulse production during 1999-2008. Ethiopia is the largest producer of chickpea in Africa, accounting for about 46% of the continent's production during 1994-2006. It is also the seventh largest producer worldwide and contributes about 2% to the total world chickpea production (Menale Kassie *et al.*, 2009). The total annual average during 1999 - 2008 chickpea production is estimated at about 173 thousand tones. During the same period, chickpea was third after faba bean and field pea in terms of area coverage (Menale Kassie *et al.*, 2009). Despite of its importance, chickpea productivity is very low. The national average yield of chickpea in Ethiopia under farmers' production condition remains less than 1.5t ha^{-1} (CSA, 2009). On the other hand, the potential of the crop under improved management condition is more than 3t ha^{-1} (Singh, 1987; Legesse Dadi *et al*., 2005). A number of limiting factors contribute to low productivity of chickpea. The major constraints are a series of abiotic and biotic stresses that reduce yield and yield stability. Among abiotic constraints, drought is the most important factor limiting chickpea production (Singh *et al*., 2008). Occurrence of drought is the common phenomenon in arid and semi-arid regions.

In the major chickpea producer countries such as India, Pakistan, Turkey and Iran, most growing areas are classified as arid or semi-arid (FAO, 2006). In these regions, chickpea is

subjected to terminal and intermittent droughts. Terminal drought sets in as drought stresses increase because of a steady depletion in soil moisture, especially towards the end of the growing season. Intermittent drought is caused by breaks in the normal rainfall pattern earlier in the growing season, these being usually associated with insufficient overall rainfall (Toker *et al*., 2007). Moreover, the chickpea crop relies on residual soil moisture in major growing areas such as India and Ethiopia without supplemental irrigation that regularly exposes the latter part of the crop's growth to terminal drought (Kumar and Abbo, 2001; Yadeta Anbessa and Geletu Bejiga, 2002). Yield losses due to drought are highly variable, depending on timing, intensity and duration, coupled with other location-specific environmental stress factors, such as high irradiance and temperature (Subbarao *et al*., 1995). Yield losses because of drought are reported as to range from 30 % to 100 %, depending on the genotypes sown and the severity and timing of drought (Leport *et al*., 1999). The problem is more serious in Ethiopia where chickpea is traditionally planted towards the end of the rainy season and generally grown on progressively declining residual soil-moisture which eventually exposes the crop to the terminal drought stress (Geletu Bejiga, *et al*., 1994). In order to increase the productivity of chickpea under drought stress, improved adaptation is required (Yadeta Anbessa and Geletu Bejiga, 2002).

Breeding for drought resistance is very complex because of stress environments are intrinsically erratic in nature and the success of the cultivars is not predictable. However, the development of resistant cultivars is hampered by low heritability for drought tolerance and a lack of effective selection strategies (Kirigwi *et al*., 2004). Therefore, seed yield and its components remain as the major selection criteria for improved adaptation to a stress environment in many breeding programs.

The relative yield performance of genotypes in drought stressed and more favorable environments seems to be a common starting point in the identification of genotypes related to drought tolerance and the selection of genotypes. In the present study, efforts have been made to quantify the relative performance of various yield attributing traits that determine seed yield in chickpea genotypes under soil moisture stress and non-stress conditions.

2. LITERATURE REVIEW

2.1. Origin and domestication of chickpea

Van der Maesen (1987) recognized the present day southeastern part of Turkey adjoining Syria as the possible center of origin of chickpea (*Cicer arietinum* L.) based on the presence of the closely related annual species, *C. reticulatum* and *C. echinospermum*, in this region.

Chickpea is also likely to have been domesticated for first time in south-east Turkey. This is supported by the distribution of early Neolithic chickpea which was confined to the Fertile Crescent, particularly in modern Anatolia and the eastern Mediterranean. In the late Neolithic era, chickpea spread westwards to modern Greece. By the Bronze Age, chickpea had been disseminated widely to Crete in the west, Upper Egypt in the south, eastwards through present-day Iraq to the Indian subcontinent. By the Iron Age, chickpea consolidated its distribution in South and West Asia, and appeared in Ethiopia for the first time (Redden and Berger, 2007).

The primary centre of diversity is in the Fertile Crescent where the crop was domesticated, and with the geographic spread of chickpea secondary centres of diversity developed, some older than 2000 years in Mediterranean, Europe, the Indian subcontinent and north-east Africa, and some more recently in Mexico and Chile with post-Colombus introduction (van der Maesen, 1972 as cited in Redden and Berger, 2007).

In line with the above idea, Muehlbauer and Rajesh (2008) added that after domestication, chickpea, along with other pulses and cereals, formed the basis of early agriculture in the Mediterranean and West Asian regions. Chickpea soon spread south to Ethiopia and east to South Asia where it became an important and popular legume food crop and remains so to the present time. According to the same authors, chickpea, apparently taken to the Americas soon after the discovery of the New World, became an important food crop in the Pacific coastal regions of North, Central, and South America.

2.2. Types of chickpea

Two distinct types of chickpea are recognized.

Desi chickpea: Chickpeas with colored and thick seed coat are called desi type. The common seed colors include various shades and combinations of brown, yellow, green and black. The seeds are generally small and angular with a rough surface. The flowers are generally pink and the plants show various degrees of anthocyanin pigmentation, although some desi types have white flowers and no anthocyanin pigmentation on the stem. The desi types account for 80-85% of chickpea area (Gaur *et al*., 2010).

Kabuli chickpea: The kabuli type chickpeas are characterized by white or beige-colored seed with ram's head shape, thin seed coat, smooth seed surface, white flowers, and lack of anthocyanin pigmentation on the stem. As compared to desi types, the kabuli types have higher levels of sucrose and lower levels of fiber. The kabuli types generally have large sized seeds and receive higher market price than desi types (Gaur *et al*., 2010).

2.3. Agro-ecology and adaptation zones of chickpea in Ethiopia

Chickpea is widely grown in different agro-ecological zones falling between 1400 to 2300m above sea level where the mean annual rainfall ranges from 700 to 2000mm (Geletu Bejiga and Million Eshete, 1996). In line with this idea, Menale Kassie *et al.* (2009) noted that the major chickpea producing areas are concentrated in the two regional states - Amhara and Oromia. These two regions cover more than 90% of the entire chickpea area and constitute about 92% of the total chickpea production. The top chickpea producing zones (North Gonder, South Gonder, North Shewa, East Gojam, South Wello, North Wello, West Gojam, and Gonder Zuria) belong to the Amhara region and account for about 80% of the country's chickpea production. In the Oromia region, the major producing zones are in West Shewa, East Shewa and North Shewa, which account for about 85% of the total area and production in this Regional State (Menale Kassie *et al.*, 2009).

2.4. Chickpea production practices in Ethiopia

Chickpea is usually grown on black vertisol. Such soils are known for excess water and drainage problem during the main rainy period (June – August). Thus, to overcome this problem farmers plant chickpea late in the season (September – October) commonly on residual moisture (Legesse Dadi *et al*., 2005). According to Geletu Bejiga and Abebe Tullu (1982), late sowing is important to avoid the unfavorable effects of water logging, diseases particularly Ascochyta leaf blight and insects.

Chickpea is weeded at least once throughout the production season. Chickpea is mainly cultivated without application of fertilizers and herbicides. Pesticides are applied on chickpea fields to control disease or insects only when a specific disease or insect epidemic occurs in a specific location (Legesse Dadi *et al*., 2005).

Chickpea harvesting is done by manual labor, either for green pod consumption or for dry seed. Harvesting time extends from October to January for green pods and February to March for harvesting dried seed (Legesse Dadi *et al*., 2005).

2.5. Major limiting factors of chickpea production

Chickpea production is exposed to different abiotic and biotic constrains which penalize seed yields. Some major limiting factors of chickpea production are discussed below.

Considerable yield losses occur due to abiotic stresses like drought, salinity, cold and frost. Resistance or tolerance to these stresses is more complex (Salimath *et al*., 2007). The most common abiotic stresses affecting chickpea production are drought (particularly terminal drought), heat and cold. In addition, there are other abiotic stresses specific to some regions such as salinity, water logging, soil alkalinity and acidity, and nutrient deficiencies and toxicities. Drought may cause complete crop failure or a varying amount of reduction in biomass and seed yield (Serraj *et al*., 2003).

The major biotic stresses which lead to yield reduction and instability are those caused by fungal, bacterial and viral diseases, insect pests and parasitic nematodes (Ranalli and Cubero, 1997).

Ascochyta blight, caused by *Ascochyta rabiei*, is a highly devastating foliar disease of chickpea in West and Central Asia, North Africa, North America and Australia. It occurs mainly in areas where cool, cloudy and humid weather prevails during the crop season (Singh, 1997; Gaur *et al*., 2007; Singh *et al*., 2008). Fusarium wilt, caused by *Fusarium oxysporum*, is the most important root disease of chickpea, particularly in the semiarid tropics where the chickpea growing season is dry and warm (Gaur *et al*., 2007).

Viral diseases have been reported to cause sporadic but significant yield loss in some areas. Major symptoms include discoloring (yellow, orange or brown) of foliage, browning of phloem and stunting of growth. Many viruses have been identified that can cause stunt disease (Gaur *et al*., 2007). Viruses isolated from chickpea include Alfalfa Mosaic, Bean Yellow Mosaic, Cucumber Mosaic, Pea Enation Mosaic, Pea Leaf Roll and Pea Streak (Winch, 2006).

Insects especially the gram caterpillar or gram pod borer (*Helicoverpa armigera* Hubner) can cause problems (Winch, 2006). The insect is highly polyphagous and sources with high levels of resistance are not available in chickpea germplasm (Gaur *et al*., 2007). Furthermore, seed beetle or bruchid (*Callosobruchus* spp.) is the most important storage pest of chickpea (Winch, 2006; Gaur *et al*., 2007). Leaf miner (*Liriomyza cicerina* Rondani) is an important insect pest of chickpea in West Asia and North Africa (WANA) and southern Europe. Efforts have been made to identify sources of resistance in the cultivated and wild species (Gaur *et al*., 2007). Cyst nematode (*Heterodera ciceri*) is another major biotic stress to chickpea (Singh *et al*., 2008).

2.6. Drought resistance in crop plants

Drought is a meteorological term and environmental event, defined as a water stress due to lack or insufficiency of rainfall and/or inadequate external water supply (Toker *et al*.,

2007). Drought stress is a complex syndrome caused by several climatic, edaphic and agronomic factors, and involves three main parameters: timing, duration and intensity (Serraj *et al*., 2003). Drought stress depends not only on rainfall and its distribution, but also on evaporation, soil water-holding capacity and crop water requirements (Toker *et al*., 2007). Drought limits the agricultural production by preventing the crop plants from expressing their full genetic potential (Mitra, 2001). Toker *et al*. (2007) added that, due to drought, the growing season may be shortened, affecting the production of yield components, which are total biomass, pod number, seed number, seed weight and quality, and seed yield per plant. In connection with this, drought reduces carbon assimilation through photosynthesis, due to limited gas exchange, and adversely affects symbiotic nitrogen-fixation processes in leguminous crops, resulting in significant reductions in crop yields and soil fertility (Serraj *et al*., 1999a as cited in Serraj *et al*., 2003). Furthermore, the problem of drought is often compounded by related stress factors, such as the infection of roots and stalks, and rot-causing fungi that cause premature death and severe lodging, all of which result in significant yield losses (Serraj *et al*., 2003).

Drought resistance is a complex trait, the expression of which depends on action and interaction of different morphological (earliness, reduced leaf area, leaf rolling, wax content, efficient rooting system, stability in yield and reduced tillering), physiological (reduced transpiration, high water-use efficiency, stomatal closure and osmotic adjustment) and biochemical (accumulation of proline, polyamine, trehalose, increased nitrate reductase activity and increased storage of carbohydrate) characters (Mitra, 2001). Little is known about the genetic mechanisms of drought resistance.

2.6.1. Mechanism of drought tolerance

Crop growth and crop water status in response to soil water deficit play an important role in tolerance to drought and in yield stability. Crops and native vegetations that are adapted to water limited conditions in terms of growth and productivity achieve adaptation mainly by various drought tolerance mechanisms. Drought tolerance refers to the ability of a crop plant to produce its economic product with minimum loss in a water-deficit environment relative to the water-constraint-free management (Mitra, 2001). In line with this, Blum

(2005) added that when a genotype yields better than another genotype under a severe strain of drought, it is relatively more drought tolerant. The mechanisms of drought tolerance can be grouped into three categories. These are drought escape, dehydration avoidance and dehydration tolerance (Mitra, 2001; Bhatnagar-Mathur e*t al*., 2010).

2.6.1.1. Drought escape

Drought escape is defined as the ability of a plant to complete its life cycle before serious soil and plant water deficits develop (Mitra, 2001). This mechanism involves rapid phenological development (early flowering and early maturity), developmental plasticity (variation in duration of growth period depending on the extent of water-deficit) and remobilization of pre-anthesis assimilates to seed (Turner, 1979 cited in Mitra, 2001).

2.6.1.2. Dehydration avoidance

Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture (Mitra, 2001; Blum, 2005). Hence, by this mechanism the plant avoids being stressed because plant functions are relatively unexposed to tissue dehydration. Crop plants avoid dehydration by enhanced capture of soil moisture, by limited crop water loss, and by retaining cellular hydration despite the reduction in plant water potential (Blum, 2005). As indicated in Mitra's review (2001) drought avoidance is performed by maintenance of turgor through increased rooting depth, efficient root system and increased hydraulic conductance and by reduction of water loss through reduced epidermal (stomatal and lenticular) conductance, reduced absorption of radiation by leaf rolling or folding.

2.6.1.3. Dehydration tolerance

Dehydration tolerance is defined as the relative capacity to sustain or conserve plant function in a dehydrated state (Blum, 2005). This mechanism of drought tolerance is achieved through changes in the biochemical composition that protect the macromolecules and membranes or maintain cell turgor through osmotic adjustment (a process which induces solute accumulation in cell), increase in elasticity in cell and decrease in cell size and desiccation tolerance by protoplasmic resistance (Bhatnagar-Mathur *et al.*, 2010*).*

2.7. Drought tolerance indices

Since drought tolerance is a quantitatively inherited trait, selection of genotypes that can tolerate drought by means of a suitable index has been a subject that breeders pay attention to. Genotypic differences in drought tolerance were compared by computing drought tolerance indices (Johansen *et al.* 1994). Drought tolerance can be estimated by comparing the performance of breeding lines under stress and non-stress (irrigated) conditions. Using data from the two water treatments, breeders can calculate drought intensity index for the experiment and the different susceptibility indices and means to assist in selection of drought tolerance genotypes. Several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions to differentiate drought tolerant genotypes. Drought susceptibility index-DSI (Fischer and Maurer, 1978), Stress tolerance-TOL and Mean productivity-MP (Rosielle and Hamblin, 1981), Geometric Mean productivity -GMP and Drought tolerance index-DTI (Fernandez, 1992) have all been used under various conditions.

The drought intensity index (DII) can be used to compare the stress between two or more experiments, the higher the value the greater the drought stress (Ramírez-Vallejo and Kelly, 1998).

Schneider *et al*. (1997) showed the geometric mean productivity (GMP) of seed yield to be the best predictor of performance in stress and non-stress environments. They recommended a breeding strategy that involved genotypic selection based first on GMP, followed by selection based on seed yield in the stress environment.

Ramirez-Vallejo and Kelly (1998) also concluded that the most effective approach to breed for tolerance to drought would be based first on selection for high geometric mean seed yields followed by selection for low Fischer and Maurer drought susceptibility index values.

2.8. Breeding approaches in chickpea for drought tolerance

Rapid expansion of water-stressed areas necessitates improvement of crops with traits such as drought tolerance and adaptation, through breeding and/or genetic manipulation (Jain and Chattopadhyay, 2010).

2.8.1. Conventional breeding to improve drought tolerance

The conventional plant-breeding approach has been generally used to develop drought-tolerant varieties (Gaur *et al*., 2007). Three breeding approaches for drought tolerance have been evolved. The first is to breed for high yield under optimum (water-stress-free) condition. It is assumed that a genotype superior under optimum level will also yield relatively well under drought condition. This is the basic philosophy of this approach. The second approach is to breed under actual drought condition (Mitra, 2001). It is based on selection for yield and its components under a given drought environment (Gaur *et al*., 2007). A genotype superior under stress condition will be recommended for drought environment. An alternative approach to the above two would be to improve drought resistance in high-yielding genotypes through incorporation of morphological and physiological mechanisms of drought resistance. However, transferring drought resistance in high-yielding genotypes is complicated due to lack of understanding of the physiological and genetic basis of adaptation in drought condition. In contrast, improving the yield potential of an already resistant material may be a more promising approach (Mitra, 2001).

2.8.2. Identification of QTLs and DNA marker related to chickpea drought tolerance

The progress in plant breeding is entirely based on the availability of genetic variation. In conventional breeding schemes, the genetic variation of breeding populations is estimated (and selected) by measuring the phenotypic performance only. Even though this process has proven to be effective, it is commonly accepted that selection directly at the genotype level, would greatly increase the efficiency of the breeding efforts. This is due to the environmental influence on the phenotypic measurements, resulting in a biased measure of the true genetic potential of an individual (Babu *et al*., 2004; Sorensen *et al*., 2007).

Identification of quantitative trait loci (QTL) is paving the way to marker assisted selection (Morgante and Salamini, 2003) and assisted pyramiding of the beneficial QTL alleles (Rehman, 2009). Although considerable progress has been made in identifying QTLs in chickpea related to fusarium wilt and ascochyta blight disease resistance, information on the genetic basis of traits related to drought tolerance in chickpea is limited. Cho *et al.* (2002) identified four QTLs for seed weight (located on LG4 and LG9), seed number per plant (LG4), and days to 50% flower (LG3).

Commonly used markers such as isozymes (Kazan and Muehlbauer, 1991), restriction fragment length polymorphisms (RFLP) (Udupa *et al.*, 1993; Simon and Muehlbauer, 1997), and random amplified polymorphic DNA (RAPD) (Simon and Muehlbauer, 1997) generally failed to reveal intraspecific variations in chickpea and their use for marker assisted selection (MAS) is therefore limited. However, simple sequence repeat (SSR) markers in chickpea were identified as being highly polymorphic compared to other types of markers (Muehlbauer and Rajesh, 2008). In addition to marker assisted selection, Tokers *et al*. (2007) suggested some promising biotechnological approaches for enhancing chickpea yield under various abiotic stresses such as embryo rescues and transformation technology.

2.9. Genetic parameters

Estimates of genetic parameters are of fundamental importance for improvement programs, as they allow the identification of the nature of a gene action involved in the control of quantitative traits and the evaluation of the efficiency of different improvement strategies at achieving genetic gains and maintaining an appropriate genetic basis (Cruz and Carneiro, 2003 as cited in Da silva *et al*., 2008).

2.9.1. Phenotypic and genotypic variance and coefficients of variability

Allard (1960) defined variability as the occurrence of difference among individuals due to differences in their genetic constitution, the environment and the interaction, in which they were raised. The actual contribution of these components differs from trait to trait. The extent of diversity in a crop determines the limits of selection for improvement (Bhargava

et al., 2007). The characters of economic importance are generally quantitative in nature and exhibit a considerable degree of interaction with environment. Thus, it becomes necessary to compute variability present in the breeding material and its partitioning into genotypic, phenotypic and environmental ones (Shukla *et al*., 2005). Improvement of yield requires an in-depth knowledge of the magnitude of variation present in the available germplasm, interdependence of quantitative characters with yield, extent of environmental influence on these factors, heritability and genetic gain of the material (Bhargava *et al*., 2007).

The estimates of genotypic and phenotypic variances provide information on the extent of variability (Malik *et al*., 2010). Atta *et al*. (2008) reported high genotypic and phenotypic variances for pods per plant followed by seed yield per plant for chickpea. Noor *et al*. (2003) revealed that medium to high genetic variance was observed for days to flowering, maturity, secondary branches and 100 seed weight. Ali *et al*. (2008) reported higher phenotypic and genotypic variances for plant height and seed yield per plant for chickpea.

According to Prasath *et al*. (2001), parameters such as genotypic and phenotypic coefficient of variability are useful in detecting the amount of variability present in germplasm. Ali *et al*. (2008) observed highest phenotypic and genotypic coefficient of variability for seed yield per plant than other traits. Atta *et al*. (2008) reported high genotypic coefficients of variation for 100 seed weight and seed yield per plant. Whereas, phenotypic coefficients of variation were high for seed yield per plant, secondary branches, pods per plant and 100 seed weight. Lowest estimates of genotypic and phenotypic coefficients of variation were recorded for days to maturity for chickpea. Yucel *et al*. (2006) reported greater phenotypic variance for DTF, PH and HI than the genotypic variance of those same traits for chickpea genotypes.

2.9.2. Heritability

Heritability estimates provide the information about index of transmissibility of the quantitative characters of economic importance and are essential for an effective crop breeding strategy. The magnitude of heritability also helps in predicting the behavior of

succeeding generations by devising the appropriate selection criteria and assessing the level of genetic improvement (Ajmal *et al*., 2009). Estimation of heritability is vital for boosting confidence during selection procedures. Characters with high heritability can easily be fixed with simple selection resulting in quick progress (Saleem *et al.,* 2002*).*

Heritability in 'Broad sense' is the ratio between the genotype variance and phenotype variance. Heritability in the 'narrow-sense' is defined as the ratio of additive genetic variance to the phenotypic variance.

Development of high-yielding varieties requires a thorough knowledge of the existing genetic variation for yield and its components. The observed variability is a combined estimate of genetic and environmental causes, of which only the former one is heritable. However, estimates of heritability alone do not provide an idea about the expected gain in the next generation, but these have to be considered in conjunction with estimates of genetic advance, the change in mean value between generations (Wani and Khan, 2006). Genetic advance gives clear picture and precise view of segregating generations for possible selection (Ajmal *et al*., 2009). Furthermore, Noor *et al.* (2003) added that characters with high heritability, coupled with high genetic advance, are supposed to be controlled additively, hence, could be exploited through simple selection.

Arshad *et al*. (2002) studied heritability and relationship of quantitative traits in thirty-six genotypes of chickpea. The result indicated that high heritability, coupled with high genetic advance, was recorded for plant height. Moderate heritability associated with high genetic advance was observed for biological yield. Whereas, primary branches, secondary branches and seed yield had low heritability associated with low genetic advance. In line with this, Saleem *et al*. (2005) reported high heritability estimates for plant height (96.9%), pods per plant (88.0%), seeds per pod (87.1%), seeds per plant (86.2%), 100-seed weight (97.7%), total weight of plant (89.8%) and seed yield per plant (90.9%) with genetic advance 11.3, 8.05, 0.10, 4.28, 3.71, 8.01 and 4.06, respectively.

2.10. Character association

2.10.1. Correlation Studies

Determination of correlation coefficients between yield and yield components is important to select favorable plant types for effective chickpea breeding. Although direct selection for the seed yield could be misleading, indirect selection via yield related characters with high heritability might be more effective than the direct selection for yield (Toker, 2004). Correlation coefficients generally show relationships among independent characteristics and the degree of linear relation between these characteristics (Guler *et al*., 2001). Correlation among the traits may be the consequence of pleiotropy or linkage/linkage disequilibrium (different loci affect traits, but these loci are linked together) among the characters (Ali *et al*., 2009).

Toker, (2004) found that biological yield was the most important character of all the traits studied due to its close relationship with seed yield. Million Eshete *et al*. (2005) studied the response of chickpea genotypes to soil moisture stress at different growth stages. They found that seed yield showed positive and significant correlation with number of pods per plant and seeds per plant under stress and non-stress conditions.

Arshad *et al*. (2004) reported that seed yield per plant was positive and significantly correlated with plant height, pods per plant, 100 seed weight and biological yield. However, it was negatively correlated with days to flowering, primary branches and harvest index under rainfed condition. Days to flowering were positively and strongly correlated with primary branches while it had negative and highly significant association with plant height. Days to maturity was positively and significantly correlated with primary branches and secondary branches. Plant height had positive and significant association with pods per plant and biological yield, but it had a high negative correlation with primary branches (Arshad *et al*., 2004). Positive and significant correlation coefficients were observed between number of pods per plant and 100-seed weight (Khan *et al*., 2006).

Determining the linear relations (correlations) among components affecting yield is insufficient to determine selection in chickpea breeding activities (Guler *et al*., 2001). Since

yield is a complex trait and it is difficult from correlations alone, to determine which traits contribute more to seed yield. Therefore, it is important to carry out path coefficient analysis so as to establish the direct and indirect contribution of each trait on seed yield (Nakawuka and Adipola, 1999).

The path coefficient is known as a standardized partial-regression coefficient, and separates the direct and indirect effects of a correlation coefficient. Path coefficient analysis has been used successfully to determine the relationships among yield and yield components (Guler *et al*., 2001). Based on path coefficient analysis, Ali *et al.* (2009) suggested that number of seeds per pod and biological yield are direct contributors towards seed yield per plant. Hence, these traits could be explored more confidently as selection criteria for yield improvement in chickpea. According to Saleem *et al*. (2002) maximum direct positive effect on seed yield per plant was exerted by number of pods per plant. Other traits, except days to maturity and number of secondary branches per plant, also had great indirect contribution to seed yield per plant via number of pods per plant.

3. OBJECTIVES

3.1. General Objective

- To evaluate yield and yield components of chickpea genotypes for genetic parameters and drought tolerance.

3.2. Specific Objectives

- To evaluate variability of chickpea genotypes for different yield parameters under moisture stress and non-stressed conditions.
- To estimate heritability and genetic advance of different quantitative traits of the chickpea genotypes under drought stress and non-stress conditions.
- To analyze the relationship between seed yield and yield components under moisture stress and non-stress conditions.
- To identify potential indicators of drought tolerance in the chickpea genotypes, and thereby suggest the most appropriate selection criteria.
- To identify chickpea genotypes that have high yield potential and high tolerance to moisture stress.

4. MATERIALS AND METHODS

4.1. Plant materials

A total of eighteen genotypes (nine kabuli and nine desi) together with four standard checks were used in the present study. The origin and some other characteristics of the test genotypes are shown in Table 1. All the genotypes were kindly provided by the National Chickpea and Lentil Improvement Project of Debre Zeit Agricultural Research Center.

Table 1. Accession number, types, flower colour, seed colour and origin of chickpea (*Cicer arietinum* L.) genotypes used in the study.

No.	Genotypes	Types	Flower colour	Seed colour	Origin
1	ICCRIL-03-0255	Desi	Pink	yellow beige	ICRISAT
2	ICC-1882	Desi	Pink	orange	ICRISAT
3	ICC-2072	Desi	Pink	brown	ICRISAT
4	ICCRIL-03-0208	Desi	Pink	ivory white	ICRISAT
5	ICCRIL-04-0087	Desi	Pink	dark brown	ICRISAT
6	ICCRIL-04-0258	Desi	Pink	yellow beige	ICRISAT
7	ICC-283	Desi	Pink	yellow	ICRISAT
8	ICC-11198	Desi	Pink	orange	ICRISAT
9	ICCRIL-03-0177	Desi	Pink	brown	ICRISAT
10	Natoli (SC)*	Desi	Pink	yellow beige	ICRISAT
11	DZ-10-11 (SC)*	Desi	Pink	brown	Ethiopia
12	ICCRIL-04-0189	Kabuli	White	ivory white	ICRISAT
13	ICC-15435	Kabuli	White	yellow	ICRISAT
14	ICCRIL-04-0166	Kabuli	White	yellow beige	ICRISAT
15	ICCRIL-04-0108	Kabuli	White	yellow beige	ICRISAT
16	ICCRIL-04-0274	Kabuli	White	ivory white	ICRISAT
17	ICC-16798	Kabuli	White	brown	ICRISAT
18	ICC-8261	Kabuli	White	yellow beige	ICRISAT
19	ICC-8151	Kabuli	White	brown beige	ICRISAT
20	ICCRIL-04-0033	Kabuli	White	yellow beige	ICRISAT
21	Habru (SC)*	Kabuli	White	orange	ICARDA
22	DZ-10-4 (SC)*	Kabuli	White	ivory white	Ethiopia

***** SC: Standard check

4.2. Experimental design

A pot experiment was carried out at Debre Zeit Agricultural Research Center during 2009 cropping season using a rainout shelter facility. Twenty two test genotypes and two water levels (stressed and non-stressed) were used to set the forty four different treatment combination of the experiment. A pot that has 30 cm diameter and 26 cm depth was used as a treatment plot. Each pot was filled with 7 Kg of homogeneous vertisol type of soil taken from the field. Plant materials were totally blocked from getting rain shower using shelter which has moveable roof. When the rain was expected to shower, the experimental materials were sheltered with the roof.

Randomized complete block design (RCBD) with three replications was employed. This means that three pots of each genotype were grown in each of the two blocks. Initially six seeds were sown in each pot and the seedlings were thinned to three plants per pot. The treatments were moisture regimes (non-stressed and stressed) and the test genotypes. Under non-stressed condition, the test genotypes were regularly watered at field capacity until maturity; while in the stress treatment re-watering of the stressed pots was done every one of five days after weighing to maintain a daily net water loss.

The weight of the pot at field capacity was determined by the following procedures as described in Million Eshete *et al*. (2005). Five pots were filled with 7 Kg of soil each and irrigated up to saturation level. The pots were then sealed with plastic sheet to avoid evaporation and allowed to drain for two days (48 hours). The weight of each pot was measured. Finally, the weight of the pot at field capacity was calculated by taking the average.

The average weight of the pot at field capacity was 9.80 Kg (that is, 9.40 Kg the weight of the soil at field capacity plus 0.4 Kg the weight of the pot). The soil water level was maintained between field capacity and 25% available water depletion for non-stressed treatment and for stressed one soil water level was maintained around 75% available soil water depletion. This was done by weighing each pot every day for well-watered control plants of each genotype to maintain at initial target weight by adding the daily water loss back to the pots.

4. 3. Characters studied

4.3.1. Yield related characters

The data on the following characters were collected from non-stressed (control) and stressed conditions.

1. **Plant height (PH):** Height of plant at the end of flowering from ground to the highest part of plant.
2. **Number of primary branches (NPB):** Average of actual count of primary branches on the main stem per plant.
3. **Number of secondary branches (NSB):** Average of number of branches arising directly from primary branches.
4. **Days to 50% flowering (DTF):** Days from sowing to the stages when 50% of the plants have started flowering per pot.
5. **Days to 90% maturity (DTM):** Days from sowing to the stages when 90% of the pods mature per pot.
6. **Number of pods (NP):** Average of actual count of both fertile and non-fertile pods per plant.
7. **Number of seeds (NS):** Average of actual count of seeds per plant.
8. **Number of seeds per pod (NSPP):** Number of seeds per plant divided by number of pods of that plant.
9. **Biological yield (BY):** Weight in gram of all above ground plant part per pot.
10. **Seed yield (SY):** the weight of seeds harvested from the pot in gram.
11. **100 seed weight (HSW):** weight of randomly selected hundred seeds weighed on a sensitive balance in gram.
12. **Harvest index (HI) (%):** the ratio of seed yield to biological yield per pot.

4.3.2. Drought tolerance indices

1. **Drought Tolerance Index (DTI):** Fernandez (1992) defined a new advanced index (DTI= Drought tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. DTI was calculated based on the Fernandez formula. $DTI = [(Yp) \times (Ys) / (Y_{AP})^2]$ where, Yp = seed yield from non-stressed pot of a given genotype, Ys = seed yield from stressed pot of that genotype, Y_{AP} = average seed yield of all genotypes from the non-stress pots.

2. **Drought susceptibility index (DSI):** DSI was calculated using the following formula set by Fisher and Maurer (1978). DSI = [(1-Ys/Yp) /DII] where, Y_S = seed yield from stressed pot of a given genotype, Y_P = seed yield from non-stressed pot of the same genotype, DII = Drought intensity index, it was calculated by the following equation.

   $$DII = [1-(Y_{AS}/Y_{AP})]$$

   Where, Y_{AS} = average seed yield of all genotypes from the stressed pots, Y_{AP} = average seed yield of all genotypes from the non-stress pots.

3. **Tolerance index (TOL):** Rosielle and Hamblin (1981) defined stress tolerance as the difference in yield between the stress (Y_S) and non-stress environment (Y_P).

   $$TOL = Y_P - Y_S$$

   Where, Y_P = seed yield from non-stressed pot of a given genotype, Y_S = seed yield from stressed pot of the same genotype.

4. **Mean Productivity (MP):** was calculated as the average yield of Y_P and Y_S.

   $$MP = Y_P + Y_S/2$$ (Rosielle and Hamblin, 1981)

   Where, Y_P = seed yield from non-stressed pot of a given genotype, Y_S = seed yield from stressed pot of the same genotype.

5. **Geometric Mean Productivity (GMP):** was calculated by using the following equation

   $$GMP = (Y_S \times Y_P)^{½}$$ (Fernandez, 1992).

   Where, Y_S = seed yield from stressed pot of a given genotype, Y_P = seed yield from non-stressed pot of the same genotype.

6. **Harmonic Mean (HARM):** was calculated through the following equation as applied by Baheri *et al*. (2003).

   $$HARM = 2(Y_P-Y_S)/ (Y_P +Y_S)$$

   Where, Y_P = seed yield from non-stressed pot of a given genotype, Y_S = seed yield from stressed pot of the same genotype.

4. 4. Data analysis

4.4.1. Analysis of variance (ANOVA)

The collected data for each character were subjected to statistical analysis of variance using SAS (SAS Institute, 2002). The analysis helps us to partition the variance into different sources (phenotypic, genotypic and environmental variance) and to see if the difference among genotypes is statistically significant or not for each trait considered. The significance of means differences were tested by Duncan's Newman Multiple Range Test (DNMRT) as stated in Gomez and Gomez (1984).

Genotypic and phenotypic variances

The variability of each trait was estimated by simple statistical measures such as mean, range, phenotypic and genotypic variances and coefficient of variation.

Variances and coefficient of variations were calculated using the following formula suggested by Singh and Chaudhary (1985).

$\sigma^2_p = \sigma^2_g + \sigma^2_e$ where; σ^2_p = Phenotypic variance,
σ^2_g = Genotypic variance,
σ^2_e = Environmental variance = Error mean square.

$\sigma^2_g = (MSg - MSe)/r$ where; MSg = Mean square of genotypes,
MSe = Mean square of error,
r = Number of replication.

$PCV = [(\sigma^2_p)^{½}/\mu] \times 100$ where, PCV = Phenotypic coefficient of variation
μ = Grand mean

$GCV = [(\sigma^2_g)^{½}/\mu] \times 100$ where, GCV = Genotypic coefficient of variation
μ = Grand mean

4.4.2. Heritability and genetic advance

Broad sense heritability (h_b^2) expressed as percentage of the ratio of the genotypic variance to the phenotypic variance. While genetic advance is improvement in genotypic value of new population as compared with base population, it depends upon the magnitude of differences among genotypic values of individuals in the base population (Allard, 1960).

4.4.2.1. Broad sense heritability (h_b^2) was calculated using the following formula given by Allard (1960).

$$h_b^2 = \sigma^2_g / \sigma^2_p \times 100$$

where, σ^2_g = Genotypic variance,

σ^2_p = Phenotypic variance.

4.4.2.2. Expected genetic advance (GA)

Genetic advance was computed by the following formula.

$$GA = K \times h_b^2 \times \sqrt{\sigma^2_p}$$ (Allard, 1960).

The genetic advance as a percentage of the mean was estimated as

$$GA\ (\%\ of\ mean) = (GA/\mu) \times 100$$

Where, k = selection differential (2.06) at 5% selection intensity.

h_b^2 = heritability, $\sqrt{\sigma^2_p}$ = phenotypic standard variation and μ = grand mean

4.4.3. Estimating of correlation coefficient and path coefficient analysis

4.4.3.1. Correlation coefficient

A matrix of simple correlation coefficients between seed yield and its components were computed with the SAS system 9.0 for window in order to determine the relationship between the examined traits and seed yield.

4.4.3.2. Path coefficient analysis

Path coefficient analysis is a procedure which examines the relations among a set of variables in order to see if they are consistent with a model of causation, in which the observed scores (events) of an object are assumed to be directly or indirectly caused by one or more preceding events. Path coefficient analysis was made on the basis of phenotypic correlation coefficients taking seed yield as effect and the remaining estimated characters as cause. Direct and indirect effects of component characters on seed yield were worked out using path coefficient analysis according to Singh and Chaundhary (1985).

The path coefficients were analyzed according to Singh and Chaundhary (1985) by using matrix method. The matrix inverse of correlation coefficients was done by using SPSS software and direct and indirect effects were calculated by using excels Microsoft Application Software.

4.4.3.3. Regression analysis

4.4.3.3.1. Multiple linear regressions

Multiple linear regression and partial coefficient of determination (R^2) were estimated for each yield component in order to evaluate the relative contribution and to develop the prediction model for seed yield according to the formula:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_nX_n.$$

Where, Y is the dependent variable, X_1, X_2… Xn are the independent variables.

a is the Y intercept and b_1, b_2,…, b_n are the partial regression coefficients.

Thus, multiple linear regression analysis procedure was performed by using SPSS (version 13.0) statistical program.

4.4.4. Biplot analysis

The biplot display of principal component analysis was used to identify stress-tolerant and high-yielding genotypes and to study the interrelationship between the stress-tolerant attributes. The principal component analysis and principal component plot were done using SAS system.

5. RESULTS

5.1. Analysis of variance

The results of analysis of variance based on randomized complete block design experiments for both water levels are presented in Appendices 1 and 2, respectively. Under non-stressed condition (Appendix 1), the mean of squares due to genotypes were highly significant for all yield attributing traits studied except for harvest index. The same trend was observed under stressed condition (Appendix 2), where the genotypes showed highly significant difference for all yield components studied, except for number of secondary branches and seed yield per plant.

5.2. Mean performance

Differences in mean performance of the chickpea genotypes for the characters studied under both non-stress and stress conditions are presented in Tables 2 and 3, respectively. The results indicated that the differences among the means of the genotypes for the studied traits were significant at 5% probability level for all experimental conditions, except harvest index for desi type chickpea genotypes under non-stress condition. Likewise, under stress condition, seed yield of desi type chickpea genotypes was not considerably influenced.

Plant height ranged from 62.33cm for DZ-10-04 genotype to 42.33 cm for ICCRIL-04-0087 genotypes under non-stress condition. Whereas, under stress condition, the highest height was recorded for ICC-8261 (40.33 cm) and the lowest height was 27.00 cm for ICC-11198. On the other hand, ICC-8151 genotype totally aborted its flower under drought stress condition. Days to flowering ranged from 73.67 days for ICC-8151 to 41 for ICC-16798 under non-stress and 76.33 for ICCRIL-04-0274 to 41 for ICCRIL-03-0177 under stress condition. Similarly, days to maturity ranged from 106.33 (ICC-8151) to 89 (ICC-16798) in non-stress and 102.33 (ICCRIL-04-0108 and ICCRIL-04-0189) to 82.33 (DZ-10-11) in stress condition. Mean pods per plant varied from 42.44 (ICC-1882) to 8.28 (ICC-8151). Under non-stress condition, where most of the tested genotypes produced their highest yield, ICC-16798 genotype produced the highest seed yield (2444 Kg ha^{-1}) followed by checks (Habru and Natoli). On the other hand, ICC-8151 showed the lowest

yield of 200 Kg ha^{-1}. Similarly, at stress water level treatment, ICC-16798 gave the highest yield of 337 Kg ha^{-1} and followed by desi check Natoli (215 Kg ha^{-1}) and ICC-11198 (196 Kg ha^{-1}).

ICC-16798 genotype produced seed yield above the average value of the Kabuli checks, Habru (1656 Kg ha^{-1}) and DZ-10-04 (883 Kg ha^{-1}), as well as the desi checks, Natoli (1402 Kg ha^{-1}) and DZ-10-11 (1053 Kg ha^{-1}), with seed yield of 2444 Kg ha^{-1} under non-stress condition. Likewise, under stress condition ICC-16798 genotype gave higher seed yield score than the check varieties with seed yield of 337 Kg ha^{-1}. Moreover, four genotypes (ICC-11198, ICC-283, ICCRIL-04-0258 and ICCRIL-03-0255) gave seed yield above the mean value of the desi checks as well as kabuli checks except Natoli (Table 3).

Mean number of seeds per plant showed that the check genotypes (DZ-10-11 and DZ-10-04) produced the highest values under non-stress and stress conditions followed by ICCRIL-04-0166 and ICC-11198 with the mean values of 38.44 and 6.06 under both moisture non-stress and stress conditions, respectively. Similarly, DZ-10-04 genotypes revealed the highest harvest index value in stress condition followed by ICC-283 genotypes with values of 8.26 and 8.24, respectively.

The weight of 100 seed varied significantly from 10.79 g to 30.02 g. The maximum seed weight was observed for the Habru (30.02g), followed by ICC-16798 (28.17g) under moisture non-stress. However, under drought stress the maximum 100 seed weight was recorded for ICC-16798 (26.39 g) and the minimum for DZ-10-04 (10.32 g).

Table 2. Mean values of yield components of chickpea genotypes per pot for non-stress environment

Genotypes	PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	SY	HI	HSW
ICCRIL-03-0255	48.67^{defg}	3.67^{abc}	7.00^{cd}	53.33^{fgh}	95.00^{bcde}	34.78^{ab}	27.22^{ab}	0.78^{bcdef}	64.13^{bc}	12.39^{bcd}	18.71^{abc}	17.13^{fghi}
ICC-1882	50.00^{def}	4.33^{ab}	8.00^{abcd}	51.67^{gh}	92.33^{cde}	42.56^{a}	33.00^{a}	0.73^{bcdef}	78.30^{bc}	14.14^{bcd}	17.11^{abc}	15.39^{hij}
ICC-2072	49.00^{defg}	3.67^{abc}	7.00^{cd}	57.33^{cdefgh}	97.67^{bcd}	32.44^{ab}	35.22^{a}	1.11^{abc}	62.45^{bc}	12.07^{bcd}	20.36^{abc}	12.13^{k}
ICCRIL-03-0208	51.67^{def}	3.33^{bc}	7.00^{cd}	54.67^{efgh}	94.33^{bcde}	34.05^{ab}	22.77^{abc}	0.68^{def}	77.59^{bc}	15.46^{bcd}	19.59^{abc}	25.09^{cd}
ICCRIL-04-0087	42.33^{g}	3.00^{c}	6.67^{cd}	53.33^{fgh}	92.33^{cde}	27.55^{abcd}	24.89^{abc}	0.90^{bcdef}	63.99^{bc}	12.073^{bcd}	19.07^{abc}	16.83^{ghi}
ICCRIL-04-0258	54.00^{cde}	4.00^{abc}	8.00^{abcd}	63.00^{bcde}	101.00^{ab}	24.66^{abcde}	26.99^{ab}	1.06^{bcd}	99.22^{ab}	13.34^{bcd}	16.18^{abc}	17.97^{efgh}
ICC-283	48.33^{defg}	3.67^{abc}	8.00^{abcd}	53.00^{fgh}	91.00^{de}	31.00^{abc}	28.33^{a}	0.92^{bcdef}	65.16^{bc}	10.72^{cde}	16.43^{abc}	13.43^{jk}
ICC-11198	53.33^{cde}	3.67^{abc}	5.67^{d}	56.33^{defgh}	90.33^{de}	39.88^{a}	35.33^{a}	0.878^{bcdef}	70.83^{bc}	12.83^{bcd}	18.23^{abc}	13.38^{jk}
ICCRIL-03-0177	45.00^{fg}	3.00^{c}	7.33^{bcd}	51.33^{h}	92.33^{cde}	33.77^{ab}	23.89^{abc}	0.70^{cdef}	70.51^{bc}	13.71^{bcd}	20.59^{abc}	22.62^{d}
Natoli*	49.00^{defg}	3.33^{bc}	8.00^{abcd}	61.00^{bcdef}	96.33^{bcde}	30.61^{abc}	23.99^{abc}	0.809^{bcdef}	90.09^{abc}	17.61^{bc}	19.54^{abc}	26.42^{bc}
DZ-10-11*	51.33^{def}	3.00^{c}	8.00^{abcd}	48.67^{h}	91.00^{de}	27.00^{abcd}	39.11^{a}	1.44^{a}	65.06^{bc}	13.23^{bcd}	19.79^{abc}	12.05^{k}
ICCRIL-04-0189	51.67^{def}	4.33^{ab}	10.00^{a}	62.67^{bcde}	97.67^{bcd}	32.94^{ab}	22.16^{abc}	0.83^{bcdef}	89.74^{abc}	11.57^{cd}	12.49^{bcd}	22.91^{d}
ICC-15435	60.00^{abc}	3.33^{bc}	10.00^{a}	66.67^{ab}	100.67^{ab}	14.27^{cde}	9.33^{cd}	0.64^{ef}	60.66^{bc}	11.31^{cd}	18.75^{abc}	18.69^{efg}
ICCRIL-04-0166	47.67^{defg}	3.00^{c}	7.00^{cd}	61.33^{bcdef}	98.33^{bcd}	38.96^{ab}	38.44^{a}	1.01^{bcde}	65.87^{bc}	14.93^{bcd}	22.87^{ab}	13.43^{jk}
ICCRIL-04-0108	47.33^{efg}	3.33^{bc}	7.67^{abcd}	66.00^{abc}	101.33^{ab}	41.72^{a}	31.67^{a}	0.77^{bcdef}	78.12^{bc}	13.05^{bcd}	16.99^{abc}	17.05^{fghi}
ICCRIL-04-0274	53.33^{cde}	4.00^{abc}	8.00^{abcd}	65.00^{bcd}	98.00^{bcd}	27.16^{abcd}	23.72^{abc}	0.873^{bcdef}	69.80^{bc}	10.66^{cde}	15.37^{abcd}	19.88^{e}
ICC-16798	50.00^{def}	4.33^{ab}	8.33^{abc}	41.00^{i}	89.00^{e}	20.67^{bcde}	23.67^{abc}	1.15^{ab}	125.01^{a}	30.70^{a}	24.56^{a}	28.17^{ab}
ICC-8261	53.67^{cde}	3.33^{bc}	9.67^{ab}	63.00^{bcde}	100.00^{abc}	10.44^{de}	9.11^{cd}	0.870^{bcdef}	76.17^{bc}	7.38^{de}	10.07^{ab}	19.59^{ef}
ICC-8151	55.00^{bcd}	3.33^{bc}	10.00^{a}	73.67^{a}	106.33^{a}	8.28^{e}	4.78^{a}	0.54^{f}	50.63^{c}	2.51^{e}	4.92^{d}	15.04^{ij}
ICCRIL-04-0033	61.00^{ab}	4.67^{a}	10.00^{a}	61.33^{bcdef}	97.33^{bcd}	12.22^{de}	11.50^{bcd}	0.95^{bcdef}	58.69^{bc}	7.29^{de}	12.66^{bcd}	15.66^{hij}
Habru*	60.00^{abc}	3.67^{abc}	7.67^{abcd}	49.67^{h}	94.33^{bcde}	25.55^{abcde}	23.11^{abc}	0.88^{bcdef}	117.53^{a}	20.80^{b}	17.55^{abc}	30.02^{a}
DZ-10-04*	62.33^{a}	4.00^{abc}	7.00^{cd}	60.33^{bcdefg}	94.33^{bcde}	35.33^{ab}	37.00^{a}	1.04^{bcde}	73.79^{bc}	11.09^{cd}	14.92^{abcd}	10.79^{k}

For each trait, means followed by the same letter (s) are not significantly different at the 5% probability level according to DMRT. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight. *; indicates the check.

Table 3. Mean values of yield components of chickpea genotypes per pot for stress environment

Genotypes	PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	SY	HI	HSW
ICCRIL-03-0255	33.67^{abcd}	3.5^{a}	5.33^{abc}	58.33^{bcdef}	95.67^{ab}	6.00^{abc}	4.16^{abcde}	0.74^{cde}	28.74^{bcd}	2.09^{bc}	7.46^{ab}	16.82^{bcd}
ICC-1882	28.33^{cd}	2.67^{bc}	5.00^{abc}	60.00^{bcde}	97.33^{ab}	3.11^{cdef}	2.44^{efg}	0.76^{cde}	26.01^{d}	1.39^{bc}	5.27^{abcd}	15.04^{defg}
ICC-2072	33.67^{abcd}	2.89^{abc}	4.67^{bc}	62.67^{bc}	95.00^{ab}	3.83^{bcdef}	5.66^{abc}	1.52^{b}	27.52^{cd}	1.97^{bc}	7.12^{abc}	11.98^{gh}
ICCRIL-03-0208	31.00^{bcd}	2.50^{c}	6.33a^{b}	53.33^{efgh}	92.67^{bc}	4.67^{abcde}	2.39^{efg}	0.53^{e}	27.12^{cd}	1.74^{bc}	6.37^{abcd}	24.83^{a}
ICCRIL-04-0087	33.33^{abcd}	2.72^{bc}	5.00^{abc}	50.33^{gh}	85.67^{cd}	3.67^{bcdef}	1.78^{efg}	0.60^{e}	27.36^{cd}	1.43^{bc}	5.23^{abcd}	16.46^{cde}
ICCRIL-04-0258	36.00^{abcd}	3.5^{a}	6.00^{abc}	52.00^{gh}	96.00^{ab}	3.22^{bcdef}	3.33^{cdefg}	1.01^{cde}	27.59^{cd}	2.17^{bc}	7.93^{a}	16.85^{bcd}
ICC-283	31.67^{abc}	2.89^{abc}	4.33^{c}	57.33^{cdef}	91.67^{bc}	6.50^{ab}	5.33^{abcd}	0.82^{cde}	28.29^{bcd}	2.23^{bc}	8.24^{a}	12.52^{fgh}
ICC-11198	27.00^{d}	2.72^{ab}	4.67^{bc}	65.00^{b}	94.67^{ab}	7.33^{a}	6.06^{ab}	0.81^{cde}	39.89^{b}	2.46^{abc}	6.13^{abcd}	12.74^{fgh}
ICCRIL-03-0177	27.33^{d}	3.00^{abc}	5.33^{abc}	41.00^{i}	93.33^{abc}	7.33^{a}	4.00^{bcdef}	0.56^{e}	27.15^{cd}	1.85^{bc}	6.94^{abc}	19.69^{h}
Natoli*	35.67^{abcd}	3.5^{a}	5.67^{abc}	60.67^{bcd}	94.67^{ab}	4.78^{abcde}	3.11^{cdefg}	0.68^{de}	39.38^{bc}	2.70^{ab}	6.88^{abc}	24.83^{a}
DZ-10-11*	30.00^{cd}	2.33^{c}	5.33^{abc}	41.33^{i}	82.33^{d}	3.89^{bcdef}	2.66^{defg}	0.64^{e}	24.27^{d}	1.52^{bc}	6.10^{abcd}	12.08^{gh}
ICCRIL-04-0189	37.00^{abc}	2.89^{abc}	5.00^{abc}	72.33^{a}	102.33^{a}	2.00^{def}	2.33^{efg}	1.11^{bcd}	25.82^{d}	1.36^{bc}	5.27^{abcd}	18.60^{bc}
ICC-15435	36.67^{abc}	2.89^{abc}	6.67^{a}	57.33^{cdef}	97.33^{ab}	2.00^{def}	1.58^{efg}	0.75^{cde}	35.13^{bcd}	1.46^{bc}	4.20^{bcde}	18.60^{bc}
ICCRIL-04-0166	29.33^{cd}	3.00^{abc}	5.67^{abc}	60.33^{bcde}	100.67^{ab}	3.83^{bcdef}	3.17^{cdefg}	0.83^{cde}	24.76^{d}	1.27^{bc}	5.16^{abcd}	13.06^{fgh}
ICCRIL-04-0108	34.00^{abcd}	2.89^{abc}	4.33^{c}	65.00^{b}	102.33^{a}	3.00^{cdef}	2.33^{efg}	0.77^{cde}	25.28^{d}	1.20^{bc}	4.74^{abcde}	15.66^{cdef}
ICCRIL-04-0274	33.00^{abcd}	2.67^{bc}	4.67^{bc}	76.33^{a}	95.67^{ab}	0.83^{f}	0.83^{g}	1.00^{cde}	26.77^{cd}	0.45^{c}	1.70^{e}	13.60^{efg}
ICC-16798	34.67^{abcd}	3.33^{ab}	4.33^{c}	47.33^{hi}	93.00^{abc}	5.22^{abcd}	3.44^{bcdefg}	0.65^{de}	50.61^{a}	4.23^{a}	7.04^{abc}	26.39^{a}
ICC-8261	40.33^{a}	2.67^{bc}	5.00^{abc}	61.67^{bc}	95.67^{ab}	0.78^{f}	1.56^{efg}	2.01^{a}	29.08^{bcd}	0.87^{bc}	3.10^{de}	16.36^{cde}
ICCRIL-04-0033	35.67^{abcd}	3.5^{a}	6.67^{a}	63.33^{bc}	99.33^{ab}	1.83^{ef}	1.33^{fg}	0.70^{cde}	25.67^{d}	1.04^{bc}	4.06^{bcde}	14.09^{defg}
Habru*	39.33^{ab}	2.83^{abc}	6.00^{abc}	54.33^{defg}	101.00^{ab}	1.78^{ef}	1.11^{g}	0.71^{cde}	27.39^{cd}	1.09^{bc}	3.72^{cde}	24.53^{a}
DZ-10-04*	28.67^{cd}	2.67^{bc}	4.67^{bc}	48.00^{gh}	92.33^{bc}	5.58^{abc}	6.66^{a}	1.16^{bc}	22.29^{d}	1.89^{bc}	8.26^{a}	10.32^{h}

For each trait, means followed by the same letter (s) are not significantly different at the 5% probability level according to DMRT. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight. *; indicates the check.

5.3. Estimates of genetic parameters

5.3.1. Estimates of phenotypic and genotypic variations

Genotypic (σ^2_g), phenotypic (σ^2_p), and environmental (σ^2_e) variances; Genotypic coefficient of variation (GCV), Phenotypic coefficient of variation (PCV) and Environmental coefficient variation (ECV) for the characters studied are presented in Tables 4 and 5, for non-stress and stress conditions, respectively. Under non-stress condition, high phenotypic (σ^2_p) and genotypic (σ^2_g) variances were observed for biological yield (BY) followed by number of pods (NP) and number of seeds (NS) per plant. Under stress condition, high phenotypic (σ^2_p) and genotypic (σ^2_g) variances were observed for days to 50% flowering (DTF) followed by biological yield (BY). On the other hand, lower phenotypic and genotypic variances were observed for number of primary branches (NPB), number of secondary branches (NSB) and number of seeds per pod (NSPP) under both non-stress and stress conditions.

Seed yield (SY), number of seeds (NS) and number of pods (NP) per plant showed the highest GCV values under non-stressed condition with values of 35.50%, 33.11% and 29.62%, respectively, whereas, number of seeds per plant, number of pods per plant and number of seeds per pod showed the highest GCV values under stress condition which are 46.94%, 44.31% and 36.64%, respectively. Lower GCV was observed for days to maturity (DTM) under both non-stress and stress conditions with values of 3.79% and 4.32%, respectively.

PCV under non-stressed and stressed conditions ranged from 49.71% to 5.71% and 67.51% to 6.57%, respectively. Among the studied characters under both non-stress and stress conditions the highest PCV was obtained for number of seeds per plant, whereas the lowest PCV was recorded for DTM under both treatment conditions.

High environmental coefficients of variation values were observed for number of seeds and number of pods per plant under stress condition but under non-stressed high values of ECV was recorded for seed yield, harvest index, number of seeds per plant and number of pods per plant. However, the lowest ECV values were observed for DTM under both stress and non-stress conditions.

From the above points, it is obvious that DTM revealed lower values for all GCV, PCV and ECV under both stress and non-stress conditions. On the other hand, NS exhibited the highest GVC and PCV values under both conditions.

5.3.2. Estimates of heritability in broad sense and genetic advance

Estimates of heritability in broad sense (h_b^2**)**, genetic advance (GA) and genetic advance as percentage of the mean (GA %) under non-stressed and stressed conditions are shown in Tables 4 and 5. Heritability estimates in broad sense for the characters under study, ranged from 28.51% to 93.35% for non-stressed and 25.31% to 88.16% for stressed conditions.

The highest broad sense heritability estimate was obtained for 100 seed weight (93.35) with 10.75 genetic advances. High heritability was also estimated for days to flowering (69.32) with expected genetic advance of 11.87. For plant height, the heritability estimate was 61.27, which can be considered as a high value. Expected genetic gain of 7.63 was noted for plant height. High broad sense heritability estimates of 51.01 with genetic advance of 6.86 were obtained for seed yield per plant. Estimation of heritability for number of seeds per plant was moderate (49.11) with high genetic advance of 12.06 under non-stressed condition. On the other hand, high estimates of heritability together with high genetic advance were recorded for 100 seed weight and day to flowering with values of 88.16 and 8.97, 84.58 and 16.59, respectively. Moreover, high heritability estimates were recorded for number of seeds per pod, number of seeds per plant and number of pod per plant with values of 64.37, 51.35 and 50.69, respectively, with low to moderate genetic advance of (0.53), (2.15) and (2.51), respectively, under stress condition.

Estimated heritability value was moderate for number of pods (45.31) and the expected genetic gain for this trait was 11.68. Days to maturity showed moderate value for heritability (44.23) with 4.99 value of genetic advance. Heritability estimates obtained for number of secondary branches as well as for number of seeds per pod were moderate (36.92) and (36.36), with low genetic advance (1.23) and (0.19), respectively, under non-stressed condition, whereas, heritability estimates for biological yield, days to maturity and number of primary branches were moderate with values of 42.02%, 43.19% and 40.20%, respectively,

together with moderate to low genetic advance (7.33), (5.56) and (0.37), respectively under stress condition.

Under non-stress condition, the broad sense heritability values for number of primary branches and biological yield were 28.51% and 31.35% and had genetic advance values of 0.39 and 0.19, respectively. These values were considered to be low for both heritability and genetic advance. Similarly, under stressed condition, heritability for plant height gave an estimate of 25.31, which was considered to be low. The expected genetic gain was 2.79. The value of heritability for harvest index was obtained as 38.07, which was a low value. The expected genetic advance for harvest index was 1.80.

The expected genetic advance as a percentage of the mean varied from 5.20% for days to maturity to 58.58% for HSW under non-stressed condition. In stressed condition, it ranged from 5.84% for days to maturity to 69.15% for number of seeds per plant.

Table 4. Estimates of genetic parameters for different yield attributes of chickpea genotypes under non-stress condition

Characters	**σ^2_p**	**σ^2_g**	**σ^2_e**	**PCV**	**GCV**	**ECV**	**h_b^2 (%)**	**GA**	**GA (% mean)**	**μ**
PH	36.54	22.39	14.15	11.62	9.09	7.23	61.27	7.63	14.66	52.03
NPB	0.46	0.13	0.33	18.74	10.01	15.82	28.51	0.39	10.99	3.63
NSB	2.61	0.96	1.65	20.19	12.27	16.06	36.92	1.23	15.37	8.00
DTF	69.13	47.92	21.21	14.35	11.95	7.95	69.32	11.87	20.49	57.92
DTM	29.98	13.26	16.72	5.71	3.79	4.26	44.23	4.99	5.20	95.95
NP	156.69	71.00	85.69	44.01	29.62	32.54	45.31	11.68	41.06	28.45
NS	142.22	69.85	72.37	47.25	33.11	33.70	49.11	12.06	47.78	25.24
NSPP	0.066	0.024	0.044	28.87	17.41	23.57	36.36	0.19	21.57	0.89
BY	627.98	196.86	431.12	32.95	18.45	27.29	31.35	7.85	10.32	76.06
SY	42.60	21.73	20.87	49.71	35.50	34.79	51.01	6.86	52.23	13.13
HI	41.06	7.31	33.75	37.43	15.79	33.93	17.80	2.35	13.73	17.12
HSW	31.27	29.19	2.08	30.47	29.44	7.86	93.35	10.75	58.58	18.35

σ^2_p = Phenotypic variance, σ^2_g = Genotypic variance, σ^2_e = Environmental variance, PCV % = Phenotypic coefficient of variation, GCV (%) = Genotypic coefficient of variation, ECV (%) = Environmental coefficient of variation, h_b^2 (%) = Heritability in broad sense, GA = Genetic advance, GA (%) = Genetic advance as percentage of mean, μ = Mean, PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight.

Table 5. Estimates of genetic parameters for different yield attributes of chickpea genotypes under stress environment

Characters	**σ^2_p**	**σ^2_g**	**σ^2_e**	**PCV (%)**	**GCV (%)**	**ECV (%)**	**h_b^2 (%)**	**GA**	**GA (% mean)**	**μ**
PH	28.64	7.25	21.39	16.14	8.12	13.95	25.31	2.79	8.41	33.16
NPB	0.199	0.08	0.119	15.22	9.65	11.77	40.20	0.37	12.59	2.93
NSB	1.13	0.24	0.889	20.19	9.37	17.89	21.54	0.47	8.92	5.27
DTF	90.65	76.67	13.98	16.55	15.22	6.50	84.58	16.59	28.84	57.52
DTM	39.05	16.87	22.18	6.57	4.32	4.95	43.19	5.56	5.84	95.17
NP	5.79	2.94	2.86	62.22	44.31	43.69	50.69	2.51	64.86	3.87
NS	4.15	2.13	2.02	65.51	46.94	45.71	51.35	2.15	69.15	3.109
NSPP	0.16	0.103	0.057	45.66	36.64	27.96	64.37	0.53	60.50	0.876
BY	71.73	30.14	41.59	28.86	18.71	21.98	42.02	7.33	24.98	29.34
SY	1.38	0.25	1.13	67.51	28.74	61.09	18.12	0.44	25.17	1.74
HI	5.28	2.01	3.27	39.89	24.61	31.39	38.07	1.80	31.25	5.76
HSW	24.40	21.51	2.89	29.25	27.46	10.06	88.16	8.97	53.11	16.89

σ^2_p = Phenotypic variance, σ^2_g = Genotypic variance, σ^2_e = Environmental variance, PCV % = Phenotypic coefficient of variation, GCV (%) = Genotypic coefficient of variation, ECV (%) = Environmental coefficient of variation, h_b^2 (%) = Heritability in broad sense, GA = Genetic advance, GA (%) = Genetic advance as percentage of mean, μ = Mean, PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight.

5.4. Relationships between seed yield and its components

5.4.1. Correlation coefficient analysis

To find out the relationships between different traits and yield, simple correlation coefficients among the studied quantitative traits of the different genotypes of chickpea used in the current study have been analyzed for each genotype under both drought stress and non-stress conditions. The correlation coefficients of quantitative characters with each other are presented in Tables 6 and 7 for both non-stress and stress treatments, respectively.

The analysis showed that strong linear relationships were found between seed yield and number of pods, number of seeds, biological yield and harvest index in both water levels. Under moisture non-stress and stress conditions, there were significant negative associations of seed yield and days to flowering (r = -0.295*; r = -0.637**) and days to maturity (r = -0.303*; r = -0.427**). However, under stress condition, the associations of PH (r = -0.098), NSB (r = -0.040), NSPP (r = -0.072) and HSW (r = 0.022) with seed yield were non-significant.

Table 6. Phenotypic correlation coefficient between yield and its components of test genotypes for non-stress condition

	PH	NPB	NSB	DF	DM	NP	NS	NSPP	BY	HI	HSW	SY
PH	1	0.273*	0.282*	0.367**	0.344**	-0.350**	-0.340**	-0.124	0.095	-0.439**	0.018	-0.247*
NPB		1	0.459**	-0.032	0.012	-0.047	-0.045	0.034	0.203	-0.103	0.030	0 .107
NSB			1	0.257*	0.316**	-0.407**	-0.400**	-0.078	0.107	-0.339**	0.147	-0.140
DTF				1	0.745**	-0.318**	-0.411**	-0.328**	-0.409**	-0.499**	-0.207	-0.637**
DTM					1	-0.323**	-0.409**	-0.321**	-0.247*	-0.370**	-0.045	-0.427**
NP						1	0.779**	-0.026	0.243*	0.470**	-0.100	0.444**
NS							1	0.557**	0.184	0.655**	-0.256*	0.548**
NSPP								1	0.089	0.405**	-0.168	0.337**
BY									1	0.064	0.482**	0.667**
HI										1	0.151	0.746**
HSW											1	0.458**

*, ** = Correlation is significant at the 0.05 and 0.01 probability level, respectively. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight.

Table 7. Phenotypic correlation coefficient between yield and its components of test genotypes for stress condition

	PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	HI	HSW	SY
PH	1	0.097	0.193	0.211	0.080	-0.358**	-0.303*	0.143	0.108	-0.215	0.322**	-0.098
NPB		1	0.273*	0.051	0.179	0.142	-0.016	-0.161	0.279*	0.238	0.221	0.354**
NSB			1	-0.036	0.012	-0.122	-0.242	-0.220	-0.023	-0.040	0.202	-0.040
DTF				1	0.504**	-0.394**	-0.221	0.287*	-0.074	-0.416**	-0.143	-0.295*
DTM					1	-0.331**	-0.260*	0.092	-0.162	-0.390**	0.114	-0.303*
NP						1	0.751**	-0.305*	0.425**	0.631**	-0.011	0.645**
NS							1	0.243	0.279*	0.740**	-0.310*	0.606**
NSPP								1	-0.105	-0.015	-0.315*	-0.072
BY									1	0.236	0.394**	0.774**
HI										1	-0.029	0.749**
HSW											1	0.220

*, ** = Correlation is significant at the 5% and 1% probability level, respectively. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight.

5.4.2. Path coefficient analysis

Path coefficient analysis was carried out in this study in order to understand the causal factors involved in determining the end product, which is seed yield. So, the correlation coefficients were partitioned into direct and indirect effects for both water levels by using path analysis as shown in Tables 8, 9, 10 and 11.

Results of the path analysis revealed that under non-stress condition, harvest index and biological yield had high positive direct effect (0.649 and 0.558, respectively) on seed yield. The same is true for drought stress in which harvest index had the highest positive direct effect (0.672) followed by biological yield (0.666). Furthermore, it was observed that the highest indirect effects on seed yield were exhibited via number of pods per plant (0.67), number of seeds per pod (0.479) and 100 seed weight (0.358) under non-stress condition. On the other hand, under drought stress condition the highest indirect positive effects were observed for number of seeds per plant (0.786) which was followed by number of pods per plant (0.555) and 100 seed weight (0.275).

Plant height showed negligible negative direct effect under both drought stress and non-stress conditions with the values of (-0.042) and (-0.016), respectively. Both primary and secondary branches also showed very meager positive direct effect on seed yield (0.066) and (0.002), respectively, under non-stress condition. Whereas, in stress condition, primary branches revealed small positive direct effect (0.011) but secondary branches showed negligible but negative direct effect (-0.0004).

Moreover, DTF had negative and small direct effect on seed yield with values of (-0.062) and (-0.021) for non-stress and stress, respectively. On the other hand, DTM had negligible negative direct effect (-0.0004) under non-stress condition, but it had positive and small direct effect under drought stress condition (0.062).

Table 8. Path coefficient analysis showing direct and indirect effects of the estimated characters on seed yield under non-stress condition.

	PH	NPB	NSB	DF	DM	NP	NS	NSPP	BY	HI	HSW
PH	**-0.0163**	0.0179	0.000698	-0.0227	-0.000155	0.07927	-0.09328	0.0177	0.0528	-0.2849	0.00176
NPB	-0.0045	**0.0656**	0.00114	0.00197	-0.0000054	0.01068	-0.01226	-0.0048	0.1131	-0.0670	0.00296
NSB	-0.0046	0.0301	**0.00248**	-0.01598	-0.000142	0.09215	-0.10966	0.0111	0.0596	-0.22003	0.01462
DTF	-0.00599	-0.0021	0.00064	**-0.06208**	-0.000335	0.07191	-0.11255	0.0468	-0.2283	-0.3241	-0.02054
DTM	-0.0056	0.00079	0.00078	-0.04624	**-0.000449**	0.07299	-0.11199	0.0459	-0.1379	-0.2405	-0.00442
NP	0.0057	-0.0031	-0.00101	0.01973	0.000145	**-0.22626**	0.21346	0.0038	0.1357	0.3054	-0.00989
NS	0.0056	-0.0029	-0.00099	0.02549	0.000184	-0.17623	**0.27406**	-0.0796	0.1027	0.4251	-0.02534
NSPP	0.00203	0.0022	-0.00019	0.02036	0.000145	0.00597	0.1527	**-0.1428**	0.0495	0.2633	-0.01663
BY	-0.00155	0.0133	0.00026	0.02541	0.000111	-0.05506	0.05048	-0.0127	**0.5576**	0.0415	0.04784
HI	0.00717	-0.0068	-0.00084	0.03098	0.000167	-0.10641	0.17942	-0.0579	0.0357	**0.64938**	0.01499
HSW	-0.00029	0.00196	0.00036	0.01286	0.00002	0.02255	-0.07002	0.0239	0.26899	0.0981	**0.09917**

Values in bold indicate direct effects. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, HI = Harvest index and HSW = 100 seed weight.

Table 9. Path coefficient analysis showing direct and indirect effects of the estimated characters on seed yield under stressed condition

	PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	HI	HSW
PH	**-0.0418**	0.00102	-0.000069	-0.0044	0.00497	-0.0324	0.0547	0.0101	0.0718	-0.1448	-0.0175
NPB	-0.00405	**0.01057**	-0.000098	-0.0011	0.0111	0.0128	0.0029	-0.0113	0.1858	0.1598	-0.1199
NSB	-0.00807	0.00289	**-0.00036**	0.0007	0.0008	-0.0111	0.0436	-0.0155	-0.0156	-0.0268	-0.011
DTF	-0.0088	0.00054	0.000013	**-0.021**	0.0315	-0.0356	0.0398	0.0202	-0.0495	-0.2796	0.0078
DTM	-0.0033	0.00189	-0.0000045	-0.0106	**0.0624**	-0.0299	0.04697	0.0065	-0.1081	-0.2621	-0.0062
NP	0.01497	0.0015	0.000044	0.0083	-0.0206	**0.0904**	-0.1355	-0.0214	0.2831	0.42404	0.00059
NS	0.0127	-0.00017	0.000087	0.0046	-0.0162	0.0679	**-0.18051**	0.0171	0.1857	0.4977	0.0168
NSPP	-0.00599	-0.0017	0.000079	-0.006	0.0058	-0.0276	-0.0439	**0.0703**	-0.06996	-0.0098	0.0171
BY	-0.0045	0.00295	0.000008	0.0016	-0.0101	0.0385	-0.0503	-0.0074	**0.6657**	0.1588	-0.0214
HI	0.009	0.0025	0.0000143	0.0087	-0.0243	0.0571	-0.1336	-0.00103	0.1573	**0.67228**	0.0016
HSW	-0.0135	0.0023	-0.0000728	0.003	0.0071	-0.00099	0.05596	-0.0221	0.2624	-0.0194	**-0.05435**

Values in bold indicate direct effects. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, HI = Harvest index and HSW = 100 seed weight.

Table 10. Path coefficient (direct and indirect effects) of the estimated yield attributes on seed yield variation of chickpea under non-stress condition

Variables	Path coefficient		Total correlation
	Direct effect	Indirect effect	
Plant height (PH)	-0.01635	-0.23098	-0.24733
Number of primary branches (NPB)	0.065631	0.041346	0.106977
Number of secondary branches (NSB)	0.002477	-0.142857	-0.14038
Days to 50% flowering (DTF)	-0.06208	-0.57451	-0.63659
Days to 90% maturity (DTM)	-0.000449	-0.426241	-0.42669
Number of pods (NP)	-0.22626	0.66997	0.44371
Number of seeds (NS)	0.274059	0.27408	0.548139
Number of seeds per pod (NSPP)	-0.14282	0.479423	0.336603
Biological yield (BY)	0.557614	0.109695	0.667309
Harvest index (HI)	0.649383	0.096495	0.745878
100 seed weight (HSW)	0.099169	0.358511	0.45768

Table 11. Path coefficient (direct and indirect effects) of the estimated yield attributes on seed yield variation of chickpea under stress condition

Variables	Path coefficient		Total correlation
	Direct effect	Indirect effect	
Plant height (PH)	-0.04182	-0.05663	-0.09845
Number of primary branches (NPB)	0.010574	0.34390	0.354475
Number of secondary branches (NSB)	-0.000364	-0.039956	-0.04032
Days to 50% flowering (DTF)	-0.02099	-0.27381	-0.2948
Days to 90% maturity (DTM)	0.062368	-0.364868	-0.3025
Number of pods (NP)	0.090452	0.554939	0.645391
Number of seeds (NS)	-0.18051	0.786284	0.605774
Number of seeds per pod (NSPP)	0.070324	-0.142084	-0.07176
Biological yield (BY)	0.665742	0.107999	0.773741
Harvest index (HI)	0.672283	0.077153	0.749436
100 seed weight (HSW)	-0.05435	0.274735	0.220385

5.4.3. Multiple linear regression analysis

Data presented in Tables 12 and 13 show regression coefficients and the probability of the estimated variables in predicting chickpea seed yield under drought non-stress and stress conditions. The obtained results showed that the prediction equations for seed yield (SY) are formulated using the chickpea plant variables in both conditions as follow:

The regression equation of SY and other yield component traits for non-stress condition:

$SY = 5.778 + 0.152\ BY + 0.688\ HI$; $R^2 = 0.988$, Adjusted $R^2 = 0.974$.

The regression equation of SY and other yield component traits under water stress regime:

$SY = -0.177 - 0.165\ NSB - 0.130\ NP + 0.077\ BY + 0.270\ HI$; $R^2 = 0.968$, Adjusted $R^2 = 0.932$.

Table 12. The regression coefficient (*b*), standard error (SE), t-value and probability of the estimated variables in predicting chickpea seed yield by the multiple linear regression analysis under non-stress condition

Variables	Coefficient of regression (*b*)	Standard error (SE)	t	Prob > | t |
Plant height (PH)	-0.079	0.091	-0.869	0.405 NS
Number of primary branches (NPB)	1.095	1.036	1.056	0.316 NS
Number of secondary branches (NSB)	0.491	0.514	0.954	0.363 NS
Days to 50% flowering (DTF)	-0.023	0.132	-0.173	0.866 NS
Days to 90% maturity (DTM)	-0.126	0.206	-0.611	0.555 NS
Number of pods (NP)	-0.378	0.215	-1.759	0.109 NS
Number of seeds (NS)	0.474	0.299	1.586	0.144 NS
Number of seeds per pods (NSPP)	-11.867	6.481	-1.831	0.097 NS
Biological yield (BY)	0.152	0.046	3.334	0.008 **
Harvest index (HI)	0.688	0.127	5.408	0.000 **
100 seed weight (HSW)	0.162	0.191	0.848	0.416 NS

**; mean significant at 1% level of probability. NS: stands for not significant. Y-intercept (a) = 5.778, SE = 16.278, $R^2 = 0.988$, Adjusted $R^2 = 0.974$.

Table 13. The regression coefficient (*b*), standard error (SE), t-value and probability of the estimated variables in predicting chickpea seed yield by the multiple linear regression analysis under stress condition.

Variables	Coefficient of regression (*b*)	Standard error (SE)	t	Prob > | t |
Plant height (PH)	-0.030	0.018	-1.716	0.120 NS
Number of primary branches (NPB)	0.230	0.157	1.469	0.176 NS
Number of secondary branches (NSB)	-0.165	0.052	-3.171	0.011 *
Days to 50% flowering (DTF)	-0.010	0.005	-1.800	0.105 NS
Days to 90% maturity (DTM)	-0.001	0.011	-0.060	0.954 NS
Number of pods (NP)	-0.130	0.053	-2.435	0.038 *
Number of seeds (NS)	0.057	0.081	0.699	0.502 NS
Number of seeds per pods (NSPP)	-0.139	0.163	-0.856	0.414 NS
Biological yield (BY)	0.077	0.008	9.633	0.000 **
Harvest index (HI)	0.270	0.054	4.960	0.001 **
100 seed weight (HSW)	0.021	0.015	1.393	0.197NS

* and **; mean significant at 5% and 1% level of probability, respectively. NS = non-significant. Y-intercept (a) = -0.177, SE = 1.052, R^2 = 0.968, Adjusted R^2 = 0.932.

Table 14. Chickpea characteristics identified as crucial in seed yield under non-stress (NS) and stress (S), by using three statistical techniques used in this study.

Variables	SC		PA		MLR		Total	
	NS	S	NS	S	NS	S	NS	S
Plant height (PH)	√						1	0
Number of primary branches (NPB)		√					0	1
Number of secondary branches (NSB)						√	0	1
Days to 50% flowering (DTF)	√	√					1	1
Days to 90% maturity (DTM)	√	√					1	1
Number of pods (NP)	√	√				√	1	2
Number of seeds (NS)	√	√					1	1
Number of seeds per pods (NSPP)	√						1	0
Biological yield (BY)	√	√	√	√	√	√	3	3
Harvest index (HI)	√	√	√	√	√	√	3	3
100 seed weight (HSW)	√						1	0

SC = Simple correlation; PA = path analysis; MLR =Multiple linear regression. Bolded variables denote the crucial character

5.5. Assessment of drought tolerance

To determine the most desirable drought tolerance criteria, the correlation coefficient between Yp, Ys and other quantitative indices of drought tolerance were calculated (Table 15). There were positive significant correlations among Yp and (MP, GMP, DTI and HARM) and Ys and (MP, GMP, DTI and HARM). The correlation coefficients for drought susceptibility index (DSI) versus seed yield under stress (Ys) was r = -0.461. No significant correlation was observed between TOL and Ys (r = 0.176, at 1% and 5% probability level). On the other hand, a strong positive correlation was observed between TOL and Y_P (r = 0.983).

A positive correlation (r = 0.352) was found between seed yield under stressed and non-stressed situations (Table 15). No significant correlations were observed between GMP and DSI (r = -0.075 at both 1% and 5% probability level).

Table 15. Correlation coefficients between Yp, Ys and drought tolerance indices

	Yp	Ys	TOL	MP	GMP	DSI	DTI	HARM
Yp	1	0.352**	0.983**	0.987**	0.724**	0.479**	0.583**	0.427**
Ys	0.352**	1	0.176NS	0.498**	0.888**	-0.460**	0.920**	0.993**
TOL	0.983**	0.176NS	1	0.941**	0.589**	0.594**	0.434**	0.256*
MP	0.987**	0.498**	0.941**	1	0.823**	0.365**	0.698**	0.566**
GMP	0.724**	0.888**	0.589**	0.823**	1	-0.075NS	0.929**	0.929**
DSI	0.479**	-0.460**	0.594**	0.365**	-0.075NS	1	-0.141NS	-0.377**
DTI	0.583**	0.920**	0.434**	0.698**	0.929**	-0.141NS	1	0.931**
HARM	0.427**	0.993**	0.256*	0.566**	0.929**	-0.377**	0.931**	1

, * and NS = Means significant at 5% and 1% probability level and NS- not significant, respectively. Yp = Yield under non-stress, Ys = Yield under stress condition, TOL = Tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, DSI = Drought susceptibility index, DTI = Drought tolerance index and HARM = Harmonic mean

Table 16. Average yields of chickpea genotypes under non-stress (Yp) and stress (Ys) conditions and estimates of drought tolerance attributes from potential yield and the stress yield data evaluated under severe stress (DII = 0.87).

Genotypes	Yp	Ys	TOL	MP	GMP	DSI	DTI	HARM
Natoli(a)	17.61	2.70	14.90	10.15	6.88	0.96	0.25	4.67
ICCRIL-04-0189(b)	11.56	1.36	10.21	6.46	3.81	0.96	0.08	2.23
ICCRIL-03-0255(c)	12.38	2.09	10.29	7.24	4.85	0.88	0.13	3.38
ICC-15435(d)	11.31	1.46	9.85	6.38	4.05	0.99	0.09	2.58
ICC-1882(e)	14.14	1.39	12.74	7.76	4.00	0.93	0.08	2.31
ICCRIL-04-0166(f)	14.92	1.27	13.65	8.10	4.36	1.05	0.10	2.34
ICC-2072(g)	12.07	1.97	10.09	7.02	4.79	0.94	0.13	3.34
ICCRIL-04-0108(h)	13.05	1.20	11.85	7.12	3.91	1.03	0.08	2.18
ICCRIL-03-0208(i)	15.45	1.74	13.72	8.59	5.08	1.01	0.14	3.08
ICCRIL-04-0274(j)	10.66	0.45	10.21	5.55	2.14	1.09	0.02	0.85
ICCRIL-04-0087(k)	12.07	1.43	10.64	6.75	4.05	0.99	0.09	2.50
Habru(l)	20.80	1.09	19.71	10.94	4.51	1.09	0.13	2.03
ICCRIL-04-0258(m)	13.34	2.17	11.16	7.75	5.15	0.88	0.15	3.56
ICC-16798(n)	30.70	4.23	26.46	17.46	10.30	0.99	0.69	6.85
ICC-283(o)	10.72	2.23	8.48	6.47	4.83	0.88	0.12	3.64
ICC-8261(p)	7.38	0.87	6.50	4.12	2.51	1.00	0.03	1.55
DZ-10-11(q)	13.23	1.52	11.71	7.37	4.25	0.98	0.10	2.63
ICC-11198(r)	12.82	2.46	10.36	7.64	5.58	0.93	0.18	4.10
DZ-10-4(s)	11.09	1.89	9.20	6.49	4.46	0.91	0.13	3.14
ICCRIL-03-0177(t)	13.71	1.85	11.85	7.78	5.03	0.99	0.13	3.26
ICCRIL-04-0033(u)	7.29	1.04	6.24	4.16	2.69	0.96	0.04	1.78
Total mean	13.63	1.73	11.89	7.68	4.63	0.97	0.14	2.95

Yp = yield under non-stress, Ys = yield under stress condition, TOL =Tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, DSI = Drought susceptibility index, DTI = Drought tolerance index and HARM = Harmonic mean. The lower case letter in front of each genotype is used to represent that genotype in biplot display.

In addition to correlation coefficient, biplot analysis was performed to illustrate the relationship between the genotypes and stress tolerance attributes in the same graph. To display the genotype by trait, two way data in biplot, a principal component analysis is necessary. The biplot display of principal component analysis was used to identify stress-tolerant and high-yielding genotypes and to study the interrelationship between the stress-tolerant attributes.

Table 17. Principal component loadings for the measured traits of chickpea genotypes

Component	Proportion of total variation (%)	Variables							
		Yp	Ys	TOL	MP	GMP	DSI	DTI	HARM
PC1	76.66	0.375	0.365	0.352	0.388	0.397	-0.035	0.393	0.369
PC2	20.72	0.268	-0.321	0.357	0.194	-0.113	0.749	-0.142	-0.292

Yp = Yield under non-stress condition, Ys = Yield under stress condition, TOL = Tolerance index, MP = Mean productivity, GMP = Geometric mean productivity, DSI = Drought susceptibility index, DTI = Drought tolerance index, HARM = Harmonic mean.

Principal component analysis (PCA) revealed that the first PC explained 76.66% of the variation with Yp, Ys, MP, GMP, DTI and HARM (Table 17) and the second PC explained 20.72% of the total variability.

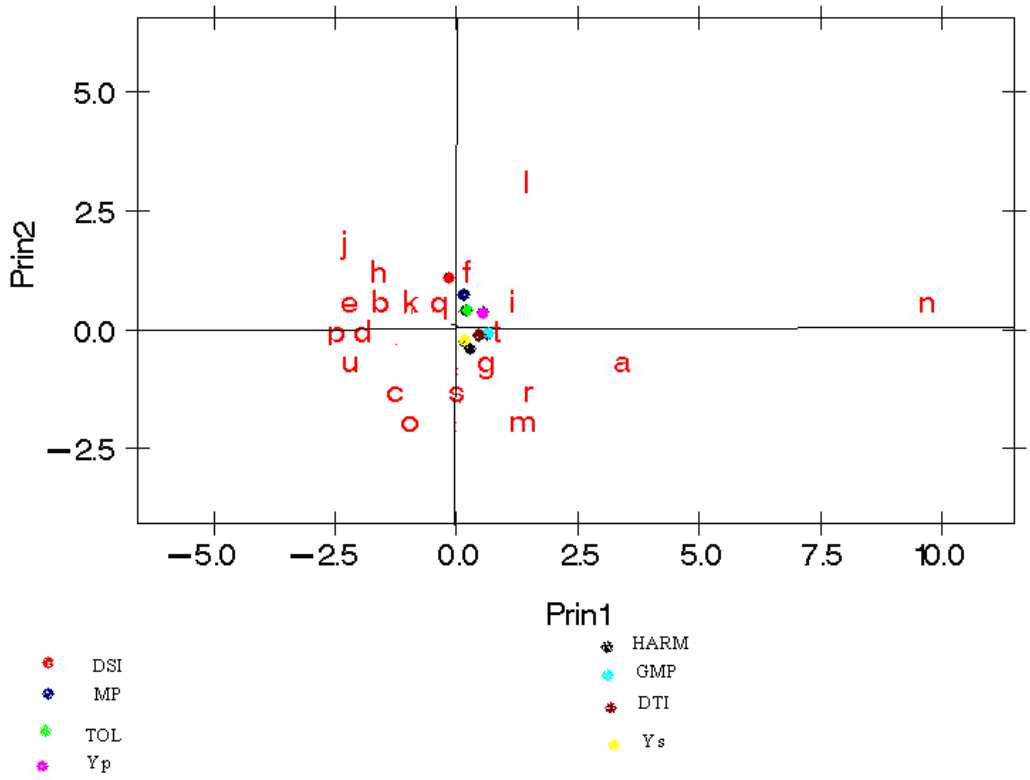


Figure 1. The genotype by trait biplots.

Each genotype is spelled out in lowercase letters, and the traits are represented by using dots with different colors. DSI= drought susceptibility index, MP= mean productivity, TOL= tolerance index, Yp= seed yield under normal conditions, HARM= harmonic mean, GMP= geometric mean productivity, DTI= drought tolerance index and Ys= seed yield under drought conditions.

6. DISCUSSION

The estimation of genetic variability is a prerequisite for breeding programs aimed at crop improvement. The evaluation of chickpea germplasm that has been undertaken in the present study revealed significant differences among the genotypes. These results indicate the existence of large genetic variability among the genotypes.

Drought is known to cause substantial reduction in seed yield of crop plants. It is a major threat to food security, sustainability of production systems, and the well being of people living in drought-prone areas. A considerable yield reduction due to water stress was observed in the present study. However, the mean values from the current study revealed that the amount of yield loss due to moisture stress mainly depend on the types of genotypes used.

The genotypes with a long delay in flowering time were associated with a larger decrease in seed yield under both environments. Therefore, longer delay in flowering time may be an indication of the genotype's susceptibility to drought, and this character may be also used as an integrative trait to identify drought tolerant genotypes. On the other hand, days to maturity under stress ranged from 82.33 days for DZ-10-11 to 102.33 for both ICCRIL-04-0189 and ICCRIL-04-0108. However, under non-stress condition, it ranged from 89 days for ICC-16798 to 106.33 days for ICC-8151. This result indicated that the range of number of days to maturity decreases in stress environment. This could be as a result of shortening of their vegetative period to escape the drought condition. This finding was in agreement with that reported by Million Eshete *et al*. (2006).

It is well known that seed yield is the final product and many characters contribute to its performance. In other words, yield depends, directly or indirectly, on the performances of other related traits. Therefore, reductions in the performances of other traits result in decrease in seed yield. Under present investigation, seed yield was significantly greater under moisture non-stress condition compared to stress condition for all the genotypes. The mean seed yield under stress condition was 138 Kg ha^{-1} which showed a reduction of

87.31% in comparison to the non-stress condition. Similar to this finding, Leport *et al*. (1999) reported that yield reduction as a result of drought range from 30 to 100% depending on the genotypes and the severity and timing of drought.

A survey of genetic variability with the help of suitable parameters such as genetic coefficient of variation, heritability estimates and genetic advance are absolutely necessary to start an efficient breeding program. In the present study, it was observed that the phenotypic variance and phenotypic coefficient of variation (PCV) were higher than the genotypic variance and genotypic coefficient of variation (GCV) for all the characters in both water levels. This indicates the presence of environmental influence in the expression of these characters. Similar results have been reported by Atta *et al*. (2008) and Khan *et al*. (2006). In support of this finding, Rahim *et al.* (2010) also reported comparable results in Mungbean. On the other hand, a small difference (less than 5%) between the PCV and GCV values was observed in days to 50% flowering, days to 90% maturity and 100 seed weight under both stress and non-stress conditions, indicating a little influence of the environment in the expression of these characters and selection for improvement of such characters based on phenotype would be rewarding to improve present chickpea genotypes.

In both experimental conditions, high phenotypic variance is correlated with high genotypic variance for biological yield. From this, it appears that there is wide scope for selection among genotypes for this characteristic based on its phenotypic appearance. On the other hand, lower phenotypic and genotypic variances were observed for number of primary branches, number of secondary branches and number of pods per plant, indicating the difficulty in improving these traits through selection. Likewise, the least phenotypic and genotypic coefficients of variation were observed for days to maturity in both water levels, and hence this trait provides practically less chance for selection. These observations are in agreement with those of Atta *et al*. (2008) who reported lowest phenotypic and genotypic coefficient of variation for days to maturity in chickpea.

Estimate of genotypic coefficients of variation alone is not sufficient to assess the heritable variation and should be considered together with heritability estimates. Heritability is a significant parameter for efficient selection and improvement of genotypes (Mohsin, *et al.*, 2009). In the present experiment, high heritability estimates were recorded for HSW and DTF under non-stress and stress conditions. The results are in agreement with Noor *et al.* (2003) and Saleem *et al.* (2002) who found high estimate of heritability for these characters. These suggest that direct selection for these traits would be effective for the improvement of yield.

Johnson *et al.* (1955) suggested that high heritability estimates, combined with high genetic advance, is indicative of additive gene action and selection based on these parameters would be more reliable. In the present investigation, high heritability estimates in conjunction with high genetic advance were observed for days to flowering and 100 seed weight under both experimental conditions. These are in line with the results obtained by Misra (1991). Furthermore, high heritability estimates coupled with high genetic gain were observed for plant height and seed yield per plant under non-stress condition, indicating that additive gene effects are more important in determining these characters and the improvement can be done through mass selection based on phenotypic values. On the other hand, high heritability coupled with low genetic advance was recorded for NSPP under stress condition, indicating the influence of dominant and epistatic genes for this character. Therefore, there appears to be a limited scope of improvement in this trait.

Seed yield is a complex character which is an outcome of interactions between a number of plant traits, which are, in turn, influenced by their genetic makeup and the environment in which they are growing. Therefore, direct evaluation may be misleading due to involvement of environmental components (Malik *et al.*, 2010). Therefore, it is very important to analyze the data for relative contribution of various components to seed yield performance using different statistical methods. Among these, simple correlation analysis is one of the important tools for this purpose. Correlation coefficients of yield and its components, estimated in this study, indicated that most of the quantitative traits

were positively and significantly correlated with seed yield under moisture stress and non-stress conditions.

Significant and positive correlation of seed yield was found with harvest index, biological yield, number of pods and number of seeds per plant under both moisture stress and non-stress conditions. These indicate that improvement in seed yield could be made through improving characters like number of pods per plant, number of seeds per plant, biological yield and harvest index. This is similar to the findings of several researchers working with chickpea. For example, Million Eshete *et al*. (2005) found that the number of pods per plant and number of seeds per plant showed significant and positive association with seed yield under optimum and water stress conditions. Toker (2004), in his field experiment, found that biological yield and number of pods per plant were positively correlated with seed yield. Toker and Cagirgan (2004) concluded biological yield and harvest index as the most important selection criteria because of their close relationship with seed yield. On the other hand, negative and significant correlations were found between DTF and SY under non-stress and stress conditions. These results suggested that the selection of plants that take less number of days to flower would increase SY per plant. Our finding is consistent with Arshad *et al*. (2004) who found negative association between DTF and SY. Furthermore, Toker (2004) and Rehman (2009) also reported similar result. Similarly, DTM also showed negative association with SY. That means early maturing genotypes give more seed yield. This indicates that early maturity is a desirable character that allows the plant to escape terminal drought. These results confirm the findings of Adane Gebreyohannes (2009).

Since the simple correlation coefficients does not give clear information about the interrelationship between the causal and resultant variables, the correlation coefficient estimates has to be partitioned into direct and indirect effects to establish the intensity of effects of independent variables on dependent one.

Path analysis identified the characters that have direct and indirect effects on seed yield. In this study, most traits were significantly correlated with seed yield. However, path analysis showed that only harvest index and biological yield had strong direct effects on

the enhancement of seed yield of chickpea in both moisture stress and non-stress conditions. It means that a direct selection through these traits will be effective. Talebi *et al*. (2007) found that biological yield and harvest index had the greatest direct effect on seed yield in kabuli chickpea. This finding is in complete agreement with the present results. Ranalli and Cubero (1997) reported that biological yield and harvest index were the major direct contributors to seed yield, and supports the present result. Arshad *et al*. (2004) reported similar type of results in chickpea under rainfed conditions. Tyagi and Khan (2010) found harvest index and biological yield showed the highest positive direct effect towards seed yield in lentil. This is also comparable with the present findings in chickpea. Moreover, DTF, DTM, NP, NS and HSW under non-stress and also NP and NS under stress conditions seemed to have the greatest importance in relation to chickpea seed yield because of their indirect effect.

On the other hand, even though the number of seeds per plant had positive correlation with seed yield, path analysis showed that its direct effect was negative under moisture stress condition. The indirect effect seems to be cause of correlation. This indicates that the indirect causal factors are to be considered simultaneously for selection.

Breeders would try to find out relationships between different characteristics in order to improve seed yield. One approach to find out relationships is by using multiple linear regression analysis. In non-stress condition, the estimate of coefficient of determination (R^2) from regression analysis explains 98.8% of the total variation within the seed yield components, while the remaining may be due to residual effects. The t-test showed that biological yield and harvest index have contributed significantly towards seed yield, while the rest variables did not. The overall results reflect the importance of the aforementioned two variables in chickpea selection for non-stress breeding programs. Under stress condition, the estimate of coefficient of determination (R^2) from regression analysis explains 96.8% of the total variation in the seed yield components. The t-test revealed that number of secondary branches, number of pods per plant, biological yield and harvest index have contributed significantly towards seed yield, while the other

variables did not have considerable contribution. This indicates that increasing NSB, NP, BY and HI can improve potential yield of chickpea under stress condition.

Summary results of the multiple statistical analyses in Table 14 showed that significant influences of harvest index and biological yield were common to both conditions. In this study, both harvest index and biological yield were not different over different water levels and also they are stable characters with respect to moisture level variations. Therefore, selection pressure should be directed towards these traits to improve the seed yield stability across different water levels.

Chickpea is believed to be fairly a drought tolerant crop, but does not mean that good growth and yields can be obtained on a very low total rainfall. However, evaluation and selection of drought-tolerant chickpea varieties have not been satisfactorily dealt with and thus continue to be a challenge that awaits chickpea breeding programmes. In other words, development of tolerant cultivars is hampered by the lack of effective selection criteria. The results from assessment of drought tolerance indicated that there was a positive and significant correlation among Yp and (MP, GMP, DTI and HARM) and Ys and (MP, GMP, DTI and HARM) and they were better predictors of Yp and Ys than TOL and DSI.

The values of the stress severity indicated as Drought Intensity Index (DII) ranges between 0 and 1 and the larger the value of DII, the more sever the stress intensity. In this study the value of DII was 0.87, it would be considered as highly sever stress.

Fernandez (1992) classified genotypes into four groups based on their performance in stress and non-stress environments: genotypes express uniform superiority in both stress and non-stress environments (Group A); genotypes perform favorably only in non-stress environments (Group B); genotypes yield relatively higher only in stress environments (Group C); and genotypes perform poorly in both stress and non-stress environments (Group D). Therefore, the optimal selection criterion should distinguish Group A from the rest.

In the present study, the correlation coefficient clearly shows that TOL has strong significant positive correlation with Yp. This indicates that selection for tolerance will be worthwhile only when the target environment is non-drought stressed. This result is consistent with Nazari and Pakniyat (2010).

Under most yield trial condition, the correlation between yield potential (Yp) and stress yield (Ys) is between 0 and 0.5 (Farshadfar and Sutka, 2002). The present results revealed that the correlation coefficient between Yp and Ys was 0.35. Thus, genotypic selection for yield under a non-stress environment would increase the mean stress yield. Correlation analysis revealed that yield potential (Yp) and stress yield (Ys) had significant and positive correlations with MP, GMP, DTI and HARM. Therefore, they can be introduced as the most desirable indices for screening drought tolerant genotypes. Similar results were obtained by Shirinzadeh *et al*. (2010) who worked on corn and found MP, GMP, DTI and HARM as preferred criteria in selection of drought tolerant genotypes. However, MP is based on the arithmetic means and therefore, it has an upward bias due to a relatively large difference between Yp and Ys, whereas, the geometric mean productivity is less sensitive to large extreme values (Fernandez, 1992). Therefore, GMP, DTI and HARM are the best criteria to select high yielding potential and drought tolerance genotypes. Similarly, Fernandez (1992) introduced GMP and DTI indices as superior criteria in selection of drought tolerant bean genotypes.

According to Fernandez (1992), DTI is estimated based on GMP and thus the rank correlation between DTI and GMP is nearly equal to 1. In the present study, the correlation between DTI and GMP was 0.93. The higher the value of DTI for a genotype the higher its stress tolerance and yield potential. The drought intensity index value is also incorporated in the estimation of DTI.

Selection based on a combination of indices may provide a more useful criterion for improving drought tolerance of chickpea genotypes but study of correlation coefficients are useful in finding the degree of overall linear association between any two attributes.

Thus, a better approach than a correlation analysis such as biplot is needed to identify the superior genotypes for both stress and non-stress environments. Genotypes subjected to biplot analysis, are simultaneously compared for assessing relationships between all the attributes (Nazari and Pakniyat, 2010).

Biplot analysis has been used by many researchers for comparison of different genotypes for different criteria and in different plant species. Kaya *et al.* (2002) were able to show that bread wheat genotypes with larger PCA1 and lower PCA2 scores gave high yields (stable genotypes) and genotypes with lower PCA1 and large PCA2 scores had low yields (unstable genotypes). Nazari and Pakniyat, (2010) selected barley genotypes that had higher PCA1 and lower PCA2 as superior genotypes under both stressed and non-stressed environments.

The present results obtained from biplot analysis (Table 17, Fig. 1) confirmed correlation analysis between studied criteria. Principal Component Analysis (PCA) revealed that the first PC explained 76.66% of the variation with Y_P, Y_S, MP, GMP, DTI and HARM (Table 17). Thus, the first dimension can be named as the yield potential and drought tolerance. The second PC explained 20.72% of the total variability. Therefore, the second component can be named as stress tolerance dimension and it separates the stress tolerant genotypes from non-stress tolerant ones. Thus, selection of genotypes that have high PC1 and low PC2 are suitable for both stress and non-stress environments. Therefore, genotypes ICC-16798, ICCRIL-04-0258, ICC-11198, ICC-2072, ICCRIL-03-0208 and ICCRIL-03-0177 with higher PC1 and lower PC2, are superior genotypes under both stressed and non-stressed conditions. These genotypes also had the highest amount of Y_P, Y_S, MP, GMP, DTI and HARM and therefore, they are desirable genotypes for both stressed and non-stressed environments. On the other hand, genotypes ICCRIL-04-0033, ICC-283 and ICCRIL-03-0255 had low yield potential under both stress and non-stress conditions.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

From the present study of chickpea genotypes, the following conclusions are made.

High heritability and genetic advances recorded for quantitative traits indicated that there is high genotypic variance in chickpea population. Therefore, selection progress could be effective through phenotypic selection for such traits and hence, they are important as a source of improvements in chickpea population.

According to the results of the strong associations found between seed yield and its components in both moisture stress and non-stress conditions, the improvement in seed yield could be made through improving characters like harvest index and biological yield. Therefore, it is concluded that harvest index and biological yield can be used as primary selection criteria for improving chickpea seed yield stability in high and low water level environments.

In the present study, GMP, DTI and HARM appear to be the most effective selection criteria for identification of high yielding potential and drought tolerant chickpea genotypes.

Based on the present findings, the following genotypes, ICC-16798, ICCRIL-04-0258, ICC-11198, ICC-2072, ICCRIL-03-0208 and ICCRIL-03-0177 are superior under both drought stress and non-stress conditions.

ICCRIL-04-0033, ICC-283, ICCRIL-03-0255 and ICC-8151 genotypes showed poor performance under moisture stress and non-stress conditions.

The checks especially Natoli and Habru are superior under both moisture non-stress and stress conditions compared to the test genotypes.

7.2. Recommendations

Based on the results of this study, the following recommendations are made for future consideration.

- ICC-16798, ICCRIL-04-0258, ICC-11198, ICC-2072, ICCRIL-03-0208 and ICCRIL-03-0177 genotypes were found to be suitable for both drought as well as drought free environments. Therefore, these genotypes should be further studied to determine their drought tolerance mechanisms.

- The identification of genotypes like ICCRIL-04-0033, ICC-283, ICCRIL-03-0255 and ICC-8151 with poor performance under moisture stress and non-stress conditions may provide useful material for comparison as drought susceptible materials in the future similar study.

- The effectiveness of selection indices in differentiating tolerant cultivars varies with the stress severity. Therefore, it is important to conduct similar study at various severity levels to select appropriate selection indices.

- Drought tolerance variability among chickpea genotypes need to be further assessed using appropriate molecular marker.

- Since the results of the present study were based on one year and one location pot experiment, studies involving more chickpea genotypes should be conducted over years and locations to find more reliable selection criteria as well as to identify genotypes which show stability of desirable traits over years and locations.

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9. APPENDICES

Appendix 1. Mean square values of yield and yield components of chickpea genotypes per pot under non-stress condition

Source of variation	Degree of freedom	Mean Square											
		PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	SY	HI	HSW
Replication	2	132.79**	0.045	0.72	186.56**	53.77	387.71*	531.37**	0.062	1056.24	165.45**	104.87	1.82
Genotypes	21	81.33**	0.73*	4.54**	164.98**	56.51**	298.69**	281.93**	0.115**	1021.69**	86.05**	55.68	89.64**
Error	42	14.15	0.33	1.65	21.21	16.72	85.69	72.37	0.044	431.12	20.87	33.75	2.08
CV (%)		7.23	15.83	16.05	7.95	4.26	32.54	33.71	23.58	27.29	34.79	33.92	7.86

* and **** = Means significant at 5% and 1% probability level, respectively. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight, CV (%) = coefficient of variation.

Appendix 2. Mean square values of yield and yield components of chickpea genotypes per pot under stress condition

Source of variation	Degree of freedom	Mean Square											
		PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	SY	HI	HSW
Replication	2	138.87**	0.027	0.206	36.33	24.97	1.96	5.13	0.096	69.125	3.95	17.27**	2.52
Genotypes	20	43.15*	0.359**	1.62	243.98**	72.787**	11.67**	8.42**	0.365**	132.0**	1.89	9.29**	67.41**
Error	40	21.39	0.119	0.889	13.98	22.184	2.859	2.018	0.057	41.586	1.13	3.27	2.89
CV (%)		13.95	11.81	17.89	6.50	4.95	43.74	45.67	27.28	21.98	61.28	31.40	10.08

*and **** = Means significant at 5% and 1% probability level, respectively. PH = Plant height, NPB = Number of primary branches, NSB = Number of secondary branches, DTF = Days to 50% flowering, DTM = Days to 90% maturity, NP = Number of pods, NS = Number of seeds, NSPP = Number of seeds per pods, BY = Biological yield, SY = Seed yield, HI = Harvest index and HSW = 100 seed weight, CV (%) = coefficient of variation.

Appendix 3. Mean, maximum and minimum values of quantitative traits of chickpea genotypes used in the present study under moisture non-stress

Accession number		PH	NPB	NSB	DF	DM	NP	NS	NSPP	BY	SY	HI	HSW
Natoli	Mean	49.00	3.33	8.00	61.00	96.33	30.61	23.99	0.81	90.08	17.61	19.54	26.42
	Max.	50.00	4.00	9.00	66.00	101.00	42.50	29.33	0.91	92.01	21.42	23.78	28.42
	Mini.	47.00	3.00	7.00	58.00	94.00	22.33	20.33	0.69	88.16	14.93	16.93	24.39
ICCRIL-04-0189	Mean	51.66	4.33	10.00	62.67	97.67	32.94	22.16	0.83	89.74	11.57	12.48	22.91
	Max.	58.00	5.00	11.00	75.00	107.00	61.00	27.67	1.05	135.49	17.98	13.28	25.93
	Mini.	48.00	4.00	9.00	56.00	90.00	18.33	19.33	0.45	43.99	4.80	10.91	19.89
ICCRIL-03-0255	Mean	48.67	3.67	7.00	53.33	95.00	34.78	27.22	0.78	64.13	12.39	18.71	17.13
	Max.	50.00	4.00	8.00	57.00	102.00	46.67	35.00	0.84	87.12	16.85	21.33	18.19
	Mini.	47.00	3.00	6.00	50.00	89.00	19.00	14.33	0.75	36.53	5.65	15.47	15.99
ICC-15435	Mean	60.0	3.33	10.00	66.67	100.67	14.28	9.33	0.64	60.66	11.31	18.75	18.69
	Max.	63.00	4.00	11.00	73.00	105.00	22.50	14.00	0.86	63.31	14.74	25.41	19.06
	Mini.	57.00	3.00	9.00	61.00	95.00	8.33	3.67	0.44	58.01	8.01	13.21	18.03
ICC-1882	Mean	50.00	4.33	8.00	51.67	92.33	42.44	33.00	0.73	78.29	14.14	17.11	15.39
	Max.	53.00	5.00	9.00	55.00	94.00	53.33	50.67	0.95	87.60	22.36	26.40	17.41
	Mini.	46.00	4.00	7.00	48.00	89.00	25.33	13.67	0.54	62.61	4.44	7.09	13.39
ICCRIL-04-0166	Mean	47.67	3.00	7.00	61.33	98.33	38.96	38.44	1.01	65.87	14.93	22.87	13.43
	Max.	52.00	3.00	8.00	66.00	103.00	50.33	43.00	1.15	71.73	15.59	25.98	15.41
	Mini.	43.00	3.00	6.00	58.00	96.00	32.22	33.00	0.85	60.01	13.72	19.13	12.43
ICC-2072	Mean	49.00	3.67	7.00	57.33	97.67	32.45	35.22	1.11	62.45	12.07	20.36	12.13
	Max.	50.00	4.00	8.00	63.00	102.00	44.00	44.00	1.18	73.43	15.12	29.37	13.27
	Mini.	48.00	3.00	6.00	53.00	95.00	20.67	24.33	1.00	46.10	7.55	11.13	10.98
ICCRIL-04-0108	Mean	47.33	3.33	7.67	66.00	101.33	41.72	31.67	0.77	78.12	13.05	16.99	17.05
	Max.	48.00	4.00	9.00	73.00	105.00	54.50	40.33	0.98	128.17	20.61	18.18	20.07
	Mini.	46.00	3.00	6.00	61.00	96.00	29.67	22.67	0.59	52.75	8.82	16.08	14.02
ICCRIL-03-0208	Mean	51.67	3.33	7.00	54.67	94.33	34.05	22.78	0.68	77.59	15.46	19.59	25.09
	Max.	56.00	4.00	9.00	59.00	95.00	43.50	27.67	0.81	89.66	18.65	20.80	25.21
	Mini.	49.00	3.00	5.00	52.00	94.00	24.33	17.33	0.54	55.95	9.64	17.23	24.98
ICCRIL-04-0274	Mean	53.33	4.00	8.00	65.00	98.00	27.17	23.72	0.87	69.79	10.66	15.37	19.88
	Max.	59.00	4.00	9.00	75.00	101.00	31.33	27.00	1.04	93.26	16.31	17.49	20.88
	Mini.	49.00	4.00	7.00	60.00	95.00	24.67	17.67	0.72	42.38	7.33	11.32	18.89
ICCRIL-04-0087	Mean	42.33	3.00	6.67	53.33	92.33	27.55	24.89	0.90	63.99	12.07	19.07	16.83
	Max.	50.00	3.00	8.00	56.00	96.00	36.33	35.00	1.00	75.26	18.43	24.49	17.83
	Mini.	36.00	3.00	5.00	49.00	87.00	21.00	18.67	0.74	44.24	8.50	11.73	14.87
Habru	Mean	60.00	3.67	7.67	49.67	94.33	25.56	23.11	0.88	117.53	20.80	17.55	30.02
	Max.	64.00	4.00	9.00	53.00	95.00	33.67	33.00	0.98	135.90	29.47	25.14	30.59
	Mini.	56.00	3.00	6.00	48.00	94.00	19.00	13.67	0.72	99.45	12.07	12.14	28.98
ICCRIL-04-0258	Mean	54.00	4.00	8.00	63.00	101.00	24.66	26.99	1.06	99.22	13.34	16.18	17.97
	Max.	64.00	5.00	9.00	66.00	102.00	31.33	39.33	1.25	118.25	20.88	31.91	18.98
	Mini.	45.00	3.00	7.00	58.00	99.00	16.33	15.33	0.94	65.43	5.18	4.38	16.97
ICC-16798	Mean	50.00	4.33	8.33	41.00	89.00	20.67	23.67	1.15	125.01	30.70	24.56	28.17
	Max.	50.00	5.00	9.00	41.00	90.00	20.67	25.00	1.15	126.67	31.70	24.83	28.98

	Mini.	50.00	4.00	8.00	41.00	88.00	20.67	22.00	1.15	123.65	29.70	24.24	27.29
ICC-283	Mean	48.33	3.67	8.00	53.00	91.00	31.00	28.33	0.92	65.16	10.72	16.43	13.43
	Max.	50.00	4.00	10.00	54.00	96.00	43.67	39.67	0.93	91.50	15.88	18.67	14.42
	Mini.	45.00	3.00	6.00	52.00	87.00	23.00	21.33	0.91	46.23	7.66	13.27	12.45
ICC-8261	Mean	53.67	3.33	9.67	63.00	100.00	10.44	9.11	0.87	76.17	7.38	10.07	19.59
	Max.	57.00	4.00	12.00	73.00	102.00	12.33	11.00	0.92	117.75	10.42	11.85	20.60
	Mini.	50.00	3.00	8.00	56.00	97.00	9.00	8.00	0.80	50.65	5.72	8.85	18.58
DZ-10-11	Mean	51.33	3.00	8.00	48.67	91.00	27.00	39.11	1.44	65.06	13.23	19.79	12.05
	Max.	57.00	4.00	9.00	50.00	96.00	34.00	49.33	2.05	70.36	17.47	25.36	12.19
	Mini.	48.00	2.00	7.00	48.00	87.00	23.00	19.67	0.85	55.95	6.67	11.92	11.97
ICC-8151	Mean	55.00	3.33	10.00	73.67	106.33	8.28	4.78	0.54	50.63	2.51	4.92	15.04
	Max.	62.00	4.00	11.00	75.00	107.00	11.50	8.00	0.70	57.86	3.38	6.92	16.04
	Mini.	50.00	3.00	9.00	73.00	105.00	3.67	1.67	0.45	45.94	0.96	1.99	14.06
ICC-11198	Mean	53.33	3.67	5.67	56.33	90.33	39.89	35.33	0.88	70.83	12.83	18.23	13.38
	Max.	56.00	4.00	6.00	57.00	94.00	48.33	46.33	0.96	84.37	17.28	20.48	14.38
	Mini.	50.00	3.00	5.00	56.00	83.00	34.33	28.67	0.84	53.11	10.39	13.85	12.39
DZ-10-4	Mean	62.33	4.00	7.00	60.33	94.33	35.33	37.00	1.04	73.78	11.09	14.92	10.79
	Max.	68.00	4.00	8.00	73.00	99.00	42.00	59.67	1.42	76.11	18.76	24.65	11.78
	Mini.	57.00	4.00	6.00	54.00	89.00	26.00	22.33	0.59	71.13	5.31	7.16	9.83
ICCRIL-03-0177	Mean	45.00	3.00	7.33	51.33	92.33	33.77	23.89	0.70	70.51	13.71	20.58	22.62
	Max.	49.00	3.00	9.00	55.00	96.00	36.67	29.67	0.81	89.41	6.14	25.03	23.64
	Mini.	41.00	3.00	6.00	49.00	87.00	31.33	18.67	0.56	56.46	10.86	12.15	21.62
ICCRIL-04-0033	Mean	61.00	4.67	10.00	61.33	97.33	12.22	11.50	0.95	58.69	7.29	12.66	15.66
	Max.	63.00	5.00	11.00	65.00	101.00	15.67	16.00	1.02	62.20	11.01	19.95	16.64
	Mini.	57.00	4.00	9.00	59.00	95.00	7.00	7.00	0.82	55.18	5.07	8.15	14.68

Appendix 4. Mean, maximum and minimum values of quantitative traits of chickpea genotypes used in the present study for moisture stress

Accession number		PH	NPB	NSB	DTF	DTM	NP	NS	NSPP	BY	SY	HI	HSW
Natoli	Mean	35.67	3.50	5.67	60.67	94.67	4.78	3.11	0.68	39.38	2.70	6.87	24.83
	Max.	38.00	4.00	6.00	66.00	96.00	5.33	4.00	1.00	43.87	2.97	6.99	26.16
	Mini.	32.00	3.00	5.00	57.00	94.00	4.00	2.00	0.38	34.90	2.44	6.77	23.16
ICCRIL-04-0189	Mean	37.00	2.89	5.00	72.33	102.33	2.00	2.33	1.11	25.82	1.36	5.27	18.60
	Max.	43.00	3.00	6.00	73.00	109.00	2.33	3.33	1.43	27.50	1.51	5.62	20.59
	Mini.	30.00	2.67	4.00	72.00	96.00	1.67	1.33	0.80	24.21	1.21	4.69	16.61
ICCRIL-03-0255	Mean	33.67	3.50	5.33	58.33	95.67	6.00	4.16	0.74	28.74	2.09	7.46	16.82
	Max.	38.00	4.00	6.00	60.00	96.00	8.00	4.33	1.00	38.62	2.58	9.23	18.11
	Mini.	31.00	3.00	5.00	57.00	95.00	4.00	4.00	0.54	22.70	1.61	6.47	16.13
ICC-15435	Mean	36.67	2.89	6.67	57.33	97.33	2.00	1.58	0.75	35.13	1.46	4.20	18.60
	Max.	39.00	3.00	8.00	59.00	101.00	3.00	2.50	0.83	39.73	1.73	5.38	19.62
	Mini.	34.00	2.67	5.00	56.00	94.00	1.00	0.67	0.67	32.15	1.19	3.55	17.59
ICC-1882	Mean	28.33	2.67	5.00	60.00	97.33	3.11	2.44	0.76	26.01	1.39	5.27	15.04
	Max.	31.00	3.00	6.00	66.00	101.00	4.33	4.00	1.00	32.77	1.91	5.97	16.05
	Mini.	25.00	2.33	4.00	56.00	95.00	2.33	1.00	0.37	21.88	0.88	4.02	14.04
ICCRIL-04-0166	Mean	29.33	3.00	5.67	60.33	100.67	3.83	3.17	0.83	24.76	1.27	5.16	13.06
	Max.	31.00	3.00	6.00	66.00	105.00	4.33	3.50	0.91	26.07	1.28	5.39	15.03
	Mini.	28.00	3.00	5.00	55.00	95.00	3.33	3.00	0.69	23.75	1.27	4.87	11.12
ICC-2072	Mean	33.67	2.89	4.67	62.67	95.00	3.83	5.66	1.52	27.52	1.97	7.12	11.98
	Max.	35.00	3.00	6.00	65.00	96.00	5.33	7.33	1.72	30.79	2.62	9.30	13.97
	Mini.	32.00	2.67	3.00	59.00	94.00	2.33	4.00	1.38	23.60	1.33	5.64	9.99
ICCRIL-04-0108	Mean	34.00	2.89	4.33	65.00	102.33	3.00	2.33	0.77	25.28	1.20	4.74	15.66
	Max.	34.00	3.00	5.00	66.00	109.00	3.67	3.00	0.82	26.14	1.41	5.39	17.69
	Mini.	34.00	2.67	4.00	64.00	96.00	2.33	1.67	0.72	24.43	0.99	3.92	13.62
ICCRIL-03-0208	Mean	31.00	2.50	6.33	53.33	92.67	4.67	2.39	0.53	27.12	1.74	6.37	24.54
	Max.	33.00	2.67	7.00	56.00	95.00	8.00	3.50	0.73	33.06	2.27	7.29	26.54
	Mini.	29.00	2.33	5.00	48.00	90.00	2.33	1.00	0.43	23.88	1.21	4.96	22.56
ICCRIL-04-0274	Mean	33.00	2.67	4.67	76.33	95.67	0.83	0.83	1.00	26.77	0.45	1.70	13.60
	Max.	36.00	3.00	5.00	80.00	96.00	1.00	1.00	1.00	28.95	0.55	2.24	15.61
	Mini.	30.00	2.33	4.00	73.00	95.00	0.67	0.67	1.00	24.60	0.35	1.31	11.59
ICCRIL-04-0087	Mean	33.33	2.72	5.00	50.33	85.67	3.67	1.77	0.60	27.36	1.43	5.23	16.46
	Max.	45.00	3.00	5.00	55.00	87.00	6.33	3.00	1.00	28.77	1.99	6.92	17.81
	Mini.	23.00	2.50	5.00	48.00	84.00	1.67	1.00	0.21	25.21	0.87	3.09	15.78
Habru	Mean	39.33	2.83	6.00	54.33	101.00	1.77	1.11	0.71	27.39	1.09	3.72	24.53
	Max.	48.00	3.00	7.00	62.00	107.00	3.67	2.33	1.00	33.84	2.02	5.97	27.52
	Mini.	35.00	2.50	5.00	48.00	95.00	0.33	0.33	0.50	24.01	0.16	0.66	21.56
ICCRIL-04-0258	Mean	36.00	3.50	6.00	52.00	96.00	3.22	3.33	1.01	27.59	2.17	7.93	16.85
	Max.	37.00	4.00	7.00	56.00	103.00	4.67	4.33	1.30	31.03	2.51	9.05	19.82
	Mini.	34.00	3.00	5.00	48.00	89.00	1.67	1.33	0.80	24.04	1.84	6.64	14.87
ICC-16798	Mean	34.67	3.33	4.33	47.33	93.00	5.22	3.44	0.65	50.61	4.23	7.04	26.39
	Max.	40.00	4.00	5.00	50.00	95.00	11.00	7.33	0.86	76.18	9.47	12.43	28.38

	Mini.	32.00	2.67	4.00	46.00	89.00	2.33	1.00	0.43	36.05	1.04	2.63	25.39
ICC-283	Mean	31.67	2.89	4.33	57.33	91.67	6.50	5.33	0.82	28.29	2.23	8.24	12.52
	Max.	34.00	3.00	5.00	61.00	94.00	7.33	5.67	0.88	35.49	2.41	10.68	14.42
	Mini.	29.00	2.67	4.00	54.00	87.00	5.67	5.00	0.77	20.92	2.06	6.79	10.45
ICC-8261	Mean	40.33	2.67	5.00	61.67	95.67	0.77	1.56	2.01	29.08	0.87	3.10	16.36
	Max.	44.00	3.00	6.00	63.00	96.00	1.00	2.00	2.03	32.80	0.88	3.90	17.07
	Mini.	33.00	2.33	4.00	60.00	95.00	0.33	0.67	2.00	22.41	0.87	2.65	15.98
DZ-10-11	Mean	30.00	2.33	5.33	41.33	82.33	3.89	2.66	0.64	24.27	1.52	6.10	12.08
	Max.	37.00	2.67	6.00	43.00	84.00	4.67	5.33	1.14	27.90	2.29	8.21	14.11
	Mini.	21.00	2.00	5.00	40.00	80.00	3.00	1.33	0.33	22.37	0.75	3.35	10.08
ICC-11198	Mean	27.00	2.72	4.67	65.00	94.67	7.33	6.06	0.81	39.89	2.46	6.13	12.74
	Max.	28.00	3.00	5.00	70.00	95.00	7.67	8.00	1.04	40.62	3.52	8.67	13.77
	Mini.	26.00	2.50	4.00	60.00	94.00	7.00	3.67	0.52	39.11	1.40	3.58	11.67
DZ-10-4	Mean	28.67	2.67	4.67	48.00	92.33	5.58	6.66	1.16	22.29	1.89	8.26	10.32
	Max.	33.00	3.00	6.00	56.00	107.00	6.67	9.33	1.40	24.55	2.89	11.77	11.31
	Mini.	20.00	2.33	4.00	43.00	83.00	4.50	4.00	0.89	20.60	0.89	4.32	9.43
ICCRIL-03-0177	Mean	27.33	3.00	5.33	41.00	93.33	7.33	4.00	0.56	27.15	1.85	6.94	19.69
	Max.	28.00	3.00	6.00	41.00	96.00	8.67	4.33	0.72	35.75	2.27	8.35	20.13
	Mini.	26.00	3.00	5.00	41.00	96.00	6.00	3.67	0.42	22.21	1.44	6.13	18.98
ICCRIL—04-0033	Mean	35.67	3.50	6.67	63.33	99.33	1.833	1.33	0.700	25.67	1.04	4.06	14.09
	Max.	45.00	4.00	8.00	66.00	105.00	2.00	2.00	1.00	28.52	1.32	5.14	14.52
	Mini.	26.00	3.00	5.00	61.00	94.00	1.67	0.67	0.40	22.82	0.77	3.37	13.78