EVALUATION ON PERFORMANCE OF CHICKPEA (*Cicer arietinum* L.) GENOTYPES UNDER WATER STRESS CONDITION

MAR MAR WIN

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EVALUATION ON PERFORMANCE OF CHICKPEA (*Cicer arietinum* L.) GENOTYPES UNDER WATER STRESS CONDITION

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MAR MAR WIN

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The thesis attached hereto, entitled **"EVALUATION ON PERFORMANCE OF CHICKPEA (*Cicer arietinum* L.) GENOTYPES UNDER WATER STRESS CONDITION"** was prepared under the direction of the chairman of the candidate supervisory committee and has been approved by all the members of that committee as a requirement for the degree of Doctor of Philosophy.

Dr. Kyaw Kyaw Win
Supervisor, Supervisory Committee
Professor and Principal
Pha-auk Campus
Yezin Agricultural University

Dr. Tun Shwe
Assistant Research Officer
Head of Food Legumes Section
Department of Agricultural Research
Yezin, Nay Pyi Taw

NangHsengHom
Dr. Nang Hseng Hom
Member, Supervisory Committee
Associate Professor
Department of Agricultural Botany
Yezin Agricultural University

Dr. Mar Mar Kyu
Member, Board of Examiners
Professor and Head
Department of Agronomy
Yezin Agricultural University

Dr. Myo Kywe
Vice-Chairman, Board of Examiners
Member, Supervisory Committee
Pro-rector (Academic)
Yezin Agricultural University

Aungkyi
Dr. Aung Kyi
Vice-Chairman, Board of Examiners
Pro-rector (Admin.)
Yezin Agricultural University

Myinthaung
Dr. Myint Thaung
Chairman, Board of Examiners
Rector
Yezin Agricultural University

Date 11-5-2011

This thesis was submitted to the Rector of the Yezin Agricultural University and was accepted as a requirement for the degree of Doctor of Philosophy.

Rector
Yezin Agricultural University

Date 11 - 5 - 2011

DECLARATION OF ORIGINALITY

This thesis represents the original works of the author, except where otherwise stated. It has not been submitted previously for a degree at any other university.

MAR MAR WIN

Date 11 - 5 - 2011

DEDICATED TO MY BELOVED PARENTS
U SAW MAUNG AND DAW KYIN SEIN

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EVALUATION ON PERFORMANCE OF CHICKPEA (*Cicer arietinum* L.) GENOTYPES UNDER WATER STRESS CONDITION

Dr. Kyaw Kyaw Win **Mar Mar Win**

ABSTRACT

Drought is the most common abiotic stress limiting chickpea production because chickpea is usually grown under the residual soil moisture. To identify and evaluate drought tolerant chickpea genotypes, the study was carried out with four experiments at Sebin Research Farm, Zaloke Research Farm, and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) during post-monsoon season of 2008-2009 and 2009-2010. The experimental materials consisted of 39 chickpea genotypes.

Chickpea genotypes were significantly different for evaluated traits under non-irrigated and irrigated conditions, indicating that drought stress increased variation for these traits. Drought stress reduced seed yield and its attributes. Mean seed yield was decreased by 21% at Zaloke and by18% at ICRISAT experiments under non-irrigated condition than irrigated condition. Five genotypes were detected with high seed yield under non-irrigated condition. They were ICCC 37 at Sebin and Zaloke, and PCHL 04-5, ICCV 03107, Annigeri and ICCV 00108 at ICRISAT. These genotypes were also observed superior to the seed yield of drought tolerant check genotype (ICC 4958) under irrigated condition. Simple correlation among the traits with seed yield showed that there was significant and positive correlation between number of pods per plant and seed yield ($r=0.41$ at $p < 0.01$) at Sebin and ($r=0.31$ at $p < 0.05$) ICRISAT experiments, and drought tolerance indices were significantly associated with seed yield at Zaloke.

The SPAD chlorophyll meter reading (SCMR) was increased but specific leaf area (SLA), and relative water content (RWC) were decreased in most of the genotypes under non-irrigated condition as compared to irrigated condition. This study also identified good performance in two genotypes for SCMR (ICCV 03110 and ICCV 00108), five genotypes for SLA (ICCV 01303, ICCV 03406, ICCV 04303, ICCV 04301 and ICCV 03302) and four genotypes for RWC (ICCC 37, Yezin 6, Karachi and ICCV 00108). Results showed that the SCMR was significantly related to seed yield ($r=0.32$ at $p < 0.05$) and SLA ($r=-0.32$ at $p < 0.05$). The genotypes having high SCMR and low SLA seemed to be resistance to drought.

Root study revealed that a large genetic variability was observed for root traits with good levels of heritability. The genotypes, PCHL 04-34, Shwenilonegi, ICCV 03103, Yezin 6 and PCHL 04-32, were found to have the largest root length density and the deepest root system. All root traits were significantly inter-correlated and associated with shoot dry weight.

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CHAPTER I
INTRODUCTION

Global population increased fourfold during the 20th century, coupled with a 4.5-fold increase in economic activity per person (Sachs 2004). The world's population is expected to increase by 50% over the next four to five decades, requiring a doubling of food output to accommodate this human expansion plus those moving up the food chain. Protein for human consumption will be in particularly short supply (Ranalli 1997). Thus, chickpea plays an important role in human nutrition as a source of protein, energy, fiber, vitamins and minerals for large population sectors in the developing world and is considered a healthy food in many developed countries. Being legume, chickpea improves physical, chemical and biological properties of soils and thus plays an important role in sustaining soil productivity. Under better management conditions, chickpea fixes up to 141 kg nitrogen per hectare (Rupela 1987).

Two distinct types of chickpea (Desi and Kabuli) are recognized based primarily on seed size, shape, and color. Chickpeas with coloured and thick seed coat are called desi type. The common seed colours 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 in the world. The split (dhal) and flour (besan) are invariably made from desi types (Gaur et al. 2010).

The kabuli types are characterized by white or beige-coloured 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 markets price than desi types. The price premium in kabuli types generally increases as the seed size increases (Gaur et al. 2010)

Chickpea is the third most important grain legume in the world after drybeans and drypeas. Its cultivation is mainly confined to Asia with 90% of the global area and production (Ali and Kumar 2001). Besides Asia, it is also grown in North and

Central America, the Mediterranean Region, the West Asian and North African (WANA) Region and Eastern Africa. Recently, the crop has expanded in new niches such as Australia and Canada. Chickpea is grown mostly as a rainfed crop under conserved moisture in the post rainy season in the semi-arid tropics and in spring and winter seasons in the temperate and Mediterranean types of climate (Ali and Kumar 2001).

Globally, chickpea is cultivated on about 11.08 million ha adding 9.77 million tons of grains to the global food baskets with an average productivity of 882 kg ha^{-1}. As many as 50 countries grow chickpea but a dozen countries *viz*., India, Pakistan, Turkey, Australia, Iran, Myanmar, Ethiopia, Canada, Mexico, Iraq, Yemen, and Syria, contribute 96% to the global production. Myanmar ranks sixth among the world top production chickpea countries. Chickpea is important legume in Myanmar, not only for local consumption but also for export earnings. After meeting the domestic demand, Myanmar is exporting surplus chickpea produce to neighboring countries. There are high demand for chickpea in India, Singapore and Pakistan. Development of kabuli variety is for international market and desi variety is for local consumption especially for army people to get daily dietary energy. The per capital pulse consumption of Myanmar was about 17.9 kg per year in 2008 (FAO 2009). The usages of chickpea are noodle, dhal (the split chickpea without its seed coat) and many kinds of snack with sugar and jaggery.

Currently, Myanmar grows chickpea on about 2.25 million ha producing 2.60 million tons of grains with an average yield of about 1155 kg ha^{-1} (FAO 2009), which constitute about 7% of the total pulses production. The majority of production area is concentrated in Sagaing (49%), Mandalay (24%) and Magway (23%) Divisions. According to its distribution throughout the country, three regions *viz*., Sagaing, Mandalay and Magway, together contribute 96% of the chickpea production (MOAI 2009). Thus, chickpea is mainly grown in the central dry zone of Myanmar. It is grown under residual soil moisture in both lowland and upland conditions. In lowland areas, it is grown as a relay or sequential crop after rice, while in upland areas it is grown mostly on fertile soil with a good water holding capacity after sesame, maize, greengram or fallow. Chickpea is also grown along the banks of Chindwin and Ayeyarwaddy Rivers after the flood water recedes. Varieties like Yezin 3 (ICCV 2) and Yezin 4 (ICCV 88202) have become quite popular among the farmers of rainfed technology mainly because of their early maturity. However, Yezin 3 and Yezin 4 are now becoming susceptible to disease in these regions (Than et al. 2007).

Chickpea faces diverse environments in these and other production areas in terms of photoperiod, temperature and precipitation, all of which have a profound effect on growth and development (Khanna-Chopra and Sinha 1987). The time of sowing and the photoperiod varies among these regions but generally most of the precipitation is received before or during the early crop season and generally the crops mature under progressively declining soil moisture and increasing temperature. In most of the chickpea growing areas, drought is a prominent characteristic which limits seed yield and can even lead to total crop failure. In both Mediterranean and sub-tropical climates, seed filling in chickpea is subject to terminal drought which limits seed yield (Turner et al. 2001). This problem is more serious in Myanmar, especially Mandalay and Magway Divisions, where chickpea is traditionally planted towards the end of the rainy season and generally grown on progressively declining residual soil-moisture. In some production areas, the rainfall is poorly distributed over the growing season and stops before growth of chickpea is completed even in case of early sowing. Economic factors do not allow the use of supplementary irrigation. Consequently, terminal drought stress, which occurs during the reproductive phase of the crop, is common and critical (Anbessa and Bejiga 2002).

Drought limits the agricultural production by preventing the crop plants from expressing their full genetic potential. Many researchers believed that tolerance to drought stress must be done via genetic improvement of seed yield in crops (Passioura 1996). Different workers used different methods to evaluate genetic differences in drought tolerance (Bidinger et al. 1982). Breeding for drought tolerance is generally considered slow due to the quantitative and temporal variability of available moisture across years, the low genotypic variance in yield under these conditions, inherent methodological difficulties in evaluating component traits, together with the highly complex genetic basis of this character. Selection for drought resistance and production of tolerant cultivars with high yield potential is the main objective of breeding programmes. However, an alternative breeding approach would be to improve drought resistance in high-yielding genotypes through incorporation of morphological and physiological mechanisms of drought resistance. Many physiological processes associated with crop growth and development is reported to be influenced by water deficits**.** In order to identify sources of drought tolerance, it is necessary to develop selection and screening methods that are simple and reproducible under the target environmental conditions (Serraj et al. 2003).

Several physiological, morphological and phenological traits have been listed to play a significant role in crop adaptation to drought stress (Ludlow and Muchow 1990; Saxena and Johansen 1990a; Subbarao et al. 1995). Alternative breeding strategies using physiological traits as selection criteria have been proposed by some researchers. Rapid progress in drought resistance breeding has been achieved based on characters such as Harvest Index (HI), Water Use Efficiency (WUE), Specific Leaf Area (SLA), and SPAD (soil plant analysis development) Chlorophyll Meter Reading (SCMR) (Nigam et al. 2005). The SLA and SCMR have been found to be highly correlated with WUE (Nageswara Rao et al. 2001; Sheshshayee et al. 2006) and have been used as surrogate traits for WUE (Nigam et al. 2005; Lal et al. 2006; Sheshshayee et al. 2006; Arunyanark et al. 2008). Specific leaf area and SCMR have been found to be negatively correlated (Nageswara Rao et al. 2001; Upadhyaya 2005).

Early studies have indicated differential responses for relative water content (RWC) in chickpea (Bahavar et al. 2009) and it was positively correlated with chlorophyll content and grain yield in rice under drought conditions (Pirdashti et al. 2009). Leaf water status is dependent on rooting density, root distribution, ability of roots to extract water, behavior of stomata closure and transpiration rate (Kramer 1983). Root systems play a crucial role in determining shoot water status and therefore effective water uptake is an important determinant of drought resistance (Huang et al. 1997; Huang 2000; Kashiwagi et al. 2006a). Larger root systems and deep growth of root systems into lower soil profile can take up more water to support plant growth and yield (Ludlow and Muchow 1990; Turner et al. 2001). Moreover, deep and prolific root systems have been associated with enhanced avoidance of terminal drought stress in chickpea (Ludlow and Muchow 1990; Serraj et al. 2004c). Selections with more extensive root systems could extract more soil water from greater soil volumes than selections with limited root system. Many root characteristics have been shown to be under genetic control and quantitatively inherited (O’Toole and Bland 1987). Genetic variation for root characters has been found among chickpea genotypes (Kashiwagi et al. 2005).

In addition, information on the heritability of RWC, SCMR, SLA, HI, biomass, seed yield, number of pods per plant, number of seeds per pod, 100-seed weight and root traits and the phenotypic correlation among these traits will be useful for planning suitable breeding strategies to improve drought tolerance. The effective selection for traits under improvement depends on sufficient additive genetic variation of the traits that are expressed as heritability. Phenotypic relationships among these traits are also important when simultaneous selection of multiple traits is to be carried out for high yield under drought stress conditions (Painawadee et al. 2009).

Efforts are needed to develop ideotype for chickpea by restructuring plant type as per the environmental requirements and prevailing cropping systems. For example, characteristics such as dense and long root system, small leaf size, early vigor, relatively few branches and early maturity along with efficient dry matter accumulation in seeds should be incorporated in breeding materials for drought-prone environment. Under conditions of cool winter followed by terminal drought such as those prevalent in the central dry zone of Myanmar, the new plant type needs to combine early flowering and tolerance to high temperature so as to avoid drought stress during pod setting. In addition, development of high yielding chickpea varieties with drought tolerance at pod setting and suitable for late planting is essential for the central dry zone of Myanmar.

Therefore, the present study was undertaken with the general objective to identify and evaluate the drought tolerant chickpea genotypes. Four experiments were conducted with the following specific objectives.

1. To evaluate the high yielding chickpea genotypes adaptable to drought-prone environment
2. To evaluate the appropriate drought tolerant genotypes with the drought tolerance indices
3. To investigate the relationship of physiological traits related to drought tolerance under non-irrigated and irrigated conditions
4. To assess the genetic variation of chickpea genotypes in root traits related to drought avoidance

CHAPTER II
REVIEW OF THE LITERATURE

2.1 Mechanisms of Drought Resistance

Drought is the most economically important abiotic constraint to crop production in the world (Boyer 1982; Araus et al. 2002). Drought can be defined as below normal precipitation that limits plant productivity (Kramer and Boyer 1995). A drought situation can be classified as either terminal or intermittent. During terminal drought, the availability of soil water decreases progressively and this leads to severe drought stress at the later period of crop growth and development. Intermittent drought is the result of finite periods of inadequate rain or irrigation occurring at one or more intervals during the growing seasons and is not necessarily lethal.

Although host-plant tolerance is an important objective in many plant breeding programs, understanding of the physiological mechanisms that contribute to variability in crop performance under drought environment remains limited (Cecerelli and Grando 1996; Passioura 1996). Plants are known to have different mechanisms to adjust to water stress condition. Plant breeders generally categorize these mechanisms into three categories — (1) drought escape, (2) drought avoidance, and (3) drought tolerance. However, some physiologists suggest that these mechanisms should be categorizes as (1) drought escape, (2) dehydration postponement, and (3) dehydration tolerance because water deficit affects the hydration of the plant (Kramer 1980; Turner 1986; Blum 1988). However, crop plants use more than one mechanism at a time to resist drought (Gaff 1980). Various morphological, physiological and biochemical characters confer drought resistance. Morphological and physiological characters show different types of inheritance pattern (monogenic and polygenic) and gene actions (additive and non-additive) (Mitra 2001). For agricultural context, drought escape and drought avoidance mechanisms are important for productivity.

2.1.1 Drought escape

Drought escape is defined as the ability of a plant to complete its life cycle before a serious plant water deficit develops. 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 preanthesis assimilates to grain (Turner 1979). Selection for early maturity is a common approach in breeding for drought resistance in crops. The early maturing crop, however, may not give higher yield in more favourable season as it cannot accumulate enough total plant biomass due to reduced total photosynthetic period compared to the relatively longer maturing varieties (Gaur et al. 2008).

2.1.2 Dehydration postponement (drought avoidance)

Dehydration avoidance is the ability of plants to maintain a relatively higher level of water potential under soil and atmospheric water stress. The process can be achieved by water uptake by the roots from deeper soil layers, by reducing water loss or by osmotic adjustment (Turner and Jones 1980; Turner 1986). Deep and large root system development is considered one of the most important components of drought tolerance in crop to extract the water from the lower soil layers as the upper layers become dry (Gregory 1988; Lawn 1988; Ludlow and Muchow 1988**)**. These are the morphological traits that are closely related to maximum exploitation of available soil water. The water loss can be reduced through stomata conductance or by reduction in leaf area (e.g. small and thick leaves). Differences in stomatal conductance of chickpea leaf in response to water potential have been reported (Lawn 1982; Muchow 1985). Other mechanisms for the control of water loss include the reduction in radiation load via change in plant canopy architecture (Mooney et al. 1977) and reduction in evaporative surface area (McMichael et al. 1973; Constable and Hearn 1978).

2.1.3 Dehydration tolerance (drought tolerance)

Dehydration tolerance refers to the ability of cells to continue metabolism at a low leaf water status (Turner et al. 2003). When water stress becomes more severe and the plant tissue is not protected from dehydration by avoidance mechanisms, cells lose turgor and dehydrate. Cellular dehydration causes significant cellular structural alterations (Poljakoff-Mayber 1981). Mechanisms related to dehydration tolerance are more or less related to survival mechanisms and not productivity. The ability of tissue to maintain turgor pressure during severe water stress is an important mechanism of dehydration tolerance (Hsiao 1973; Hsiao et al. 1976). Most of the dehydration tolerance traits studied are primarily involved with protection of cellular structure from the effect of dehydration. Several types of protective proteins including dehydrins and late-embryogenesis abundant (LEA) proteins are known to be accumulated in response to decrease in tissue water content (Close 1997). These proteins act as chaperones that protect protein and membrane structure (Hara et al. 2001; Bravo et al. 2003). Compatible solutes can also protect protein and membrane structure under dehydration (Hincha and Hagemann, 2004). The role of reactive oxygen species (ROS) in stress signaling have been extensively studied in recent years and reviewed (Chen and Gallie 2004; Hung et al. 2005).

An important point to consider is that stressful environments are often characterized by the simultaneous or sequential occurrence of more than one stress. For example, salinity is often associated with drought or water logging, and drought is often associated with high temperature (Flowers and Yeo 1986; Guilioni et al. 2003). The consideration of tolerance mechanisms depends upon the objectives of the researcher and the pattern of drought stress or host organism. Plant breeders and agronomists may be interested in drought resistance mechanisms related to productivity (drought escape and dehydration avoidance) while ecologists may be interested in mechanisms related to survival (dehydration tolerance).

2.2 Drought and Chickpea

Drought is the most common abiotic stress limiting chickpea production in different parts of the world. Ninety percent of the world's chickpea was produced in areas relying upon conserved, receding soil moisture (Kumar and Abbo 2001). Chickpea frequently suffers from drought stress towards the end of the growing season in rainfed condition. The extent of terminal drought stress varies depending on previous rainfall, atmospheric evaporative demand, and soil characteristics such as type, depth, structure, and texture. Terminal drought is globally the most serious constraint to chickpea productivity. It is estimated that if the soil water stress is alleviated, chickpea production could be improved up to 50% that is equivalent to approximately 900 million US dollars (Ryan 1997). Therefore, crop productivity is largely dependent on efficient utilization of available soil moisture (Kumar and Van Rheenen 2000). Although chickpea is well adapted to growing on conserved moisture in drought prone environment, still drought is a major yield reducer (ICRISAT 1996).

2.3 Chickpea Research Related to Drought Tolerance

In chickpea, the focus of drought tolerance research is on the ability to sustain greater biomass production and crop yield under seasonally increasing water deficit rather than the physiological aptitude for plant survival under extreme drought shock (Serraj and Sinclair 2002). This has led to the focus on escape and avoidance strategies such as early maturity (Kumar and Abbo 2001) and large root systems (Saxena et al. 1995; Singh et al. 1995; Kashiwagi et al. 2005).

2.3.1 Early maturity in chickpea

Early maturing chickpea varieties that escape terminal drought have been developed (Kumar and Abbo 2001), but early maturity places a ceiling on the potential yield and limits the crop's ability to exploit extended growing periods. Chickpea genotypes with high growth vigor are early maturity. Selection for high growth vigor enhances chance for escaping terminal drought stress (Sabaghpour and Kumar 2002). Initial growth vigor is suitable character for large-scale evaluation of germplasm and breeding materials (Sabaghpour et al. 2003). The initial growth vigor rated on a 1-5 scale (1=Very good, 2=Good, 3=Average, 4= poor and 5= very poor) in accordance with International Center for Agricultural Research in the Dry Areas (ICARDA) (Sabaghpour et al. 2006).

2.3.2 Root traits for drought avoidance

Extensive and deep root systems have been recognized as one of the most important traits for improving crop productivity under progressively receding soil moisture condition. Field studies in legumes showed that both dense root systems extracting more of the water in upper soil layers and longer root systems extracting soil moisture from deeper soil layers are important for maintaining yield under terminal drought stress (Saxena and Johansen 1990b; Turner et al. 2001). Kashiwagi et al. (2006a) found substantial variation in root length density among 12 diverse kabuli and desi chickpea genotypes at different soil moisture levels. The proportion of the roots at the lower depth was also important in water absorption from deeper soil layers. The root traits such as biomass, length density and depths have been proposed as the main drought avoidance traits to contribute to seed yield under terminal drought environment (Kashiwagi et al. 2006a). Therefore, phenotypic information on root traits of field-grown plants is a pre-requisite to breed the genotypes with improved root system.

Roots have a major role in dehydration avoidance as deep root system is able to obtain moisture from the deeper soil layers even when the upper soil layer becomes dry. The advantage of a deep root system towards drought tolerance was also substantiated in soybeans (Kaspar et al. 1978), common beans (Sponchiado et al. 1989) and chickpea (Silim and Saxena 1993). Some major root attributes such as greater efficiency in water absorption per unit root length density, ability to change the rooting pattern across soil depths to efficiently access the available soil moisture and the ability to produce a larger root surface area per unit root biomass seem to make chickpea the best choice for the dry land cropping systems compared to other legumes or cereal (Thomas et al. 1995; Ali et al. 2002; Tilahun and Schubert 2003; Benjamin and Nielsen 2006). Chickpea have the ability to change their root distribution across soil depths depending on the soil moisture availability (Ali et al. 2002). Benjamin and Nielsen (2006) reported that greater root surface area to weight ratio in chickpea as compared to field pea and soybean indicates either a finer root system or roots with lower specific density. Those results suggest that chickpea are better equipped towards tolerance to drought stress and further improvement of root traits would be one of the promising approaches to improve the drought avoidance of chickpea under the terminal drought environments. Nowadays, research on chickpea is focused on the use of molecular markers for various root traits including rooting depth, root volume and root thickness to improve drought avoidance (Serraj et al. 2004a; Gaur et al. 2008).

2.4 Crop Improvement Strategies for Drought Tolerance

2.4.1 Improving adaptability over all environment

Most of the breeding programs for improved yield of grain legumes rely on empirical selection for superior seed yield and quality across a wide range of target environments (Turner et al. 2001). While direct selection for seed yield can be effective, the approach is difficult and costly, and gains from selection are often low, especially in drought-prone environments (White et al. 1994). Moreover, the inheritance or repeatability of seed yield is very low, which is indicative that the observed variation that is attributed to genetic effects (G) is relatively small in comparison to variations observed due to environmental effects (E) and that just as different grain legumes species respond differently to different environment, so different genotypes respond differently depending on environment (G x E) (Blum 1988; Williams 1992). The progress in breeding for drought tolerance is slow due to the quantitative and temporal variability of available moisture across years, the low genotypic variance in yield under these conditions and inherent methodological difficulties in evaluating components traits together with the highly complex genetic basis of this character (Turner et al. 2001). Several physiological, morphological and phonological traits may play a significant role in crop adaptation to drought stress during soil drying (Serraj et al. 2004a). Any effort for genetic improvement in drought resistance utilizing the existing genetic variability requires an efficient screening technique, which should be rapid and capable of evaluating plant performance at the critical developmental stages and screening a large population using only a small sample of plant material. A combination of different traits of direct relevance, rather than a single trait, should be used as selection criteria.

2.4.2 Selection criteria for assessing drought stress tolerance

In agriculture, drought resistance 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. To evaluate response of plant genotypes to drought stress, some selection indices based on a mathematical relation between stress and optimum conditions has been proposed (Rosielle and Hamblin 1981; Clarke et al. 1992; Fernandez 1992; Sio-Se Mardeh et al. 2006). In order to increase the productivity of chickpea under drought stress, improved adaptation is required. Chickpea genotypes that are tolerant / resistant to drought have been reported (Saxena et al. 1993b; Johansen et al. 1994). For example, promising drought tolerant line ICC 4958 was identified by line-source sprinkler irrigation method and further validated by drought susceptibility index (DSI). The DSI proposed by Fisher and Maurer (1978) was calculated based on yield under rainfed conditions and potential yield under irrigated conditions. The lower the DSI, the greater is the drought tolerance of the genotype. The drought tolerance efficiency (DTE) calculated by Deshmukh et al. (2004) was used for field screening of chickpea genotypes for drought resistance. The drought resistant genotype had highest DTE, minimum DSI and minimum reduction in seed yield due to moisture stress (Deshmukh et al. 2004). Toker and Cagirgan (1998) determined the best tolerance chickpea lines to drought stress with biological yield, harvest index, Mean Productivity (MP), Tolerance Index (TOL), and DSI. Jafari et al. (2009) evaluated drought tolerance of corn using with different selection indices such as Stress Susceptibility Index (SSI), Harmonic Mean (Harm), Tolerance Index (TOL), MP, Stress Tolerance Index (STI), and Geometric Mean Productivity (GMP). Moreover, the efficiency of GMP and STI indices were reported in identifying and selection of drought resistant cultivars in safflower (Purdad 2004; Arslan 2007; Ashkani et al. 2007) and in pearl millet (Yadav and Bhatnagar 2001). Abebe et al. (1988) compared yield-based selection indices for identifying high yielding dry bean lines under drought and optimum conditions.

2.5 Characterization of Drought Resistance Traits

Identification of simple to observe morphological and phonological traits, reflective of mechanisms and processes that confer drought tolerance has been a high priority activity in drought research. An appropriate screening trait for drought stress tolerance should fill the following criteria: (i) a strong link with higher or more stable grain yield in the target stress environment, (ii) a high level of heritability, and (iii) the expression of tolerance must be easily measurable, with adequate replication (Serraj et al. 2003).

A number of physiological, morphological and phonological traits/responses have been associated with drought stress adaptation. Important putative drought resistance traits for crop include: yield and its components, HI under drought, grain fill duration and rate, grain number maintenance, staygreen/delayed senescence, canopy temperature, osmotic adjustment/RWC, hormonal regulation, deep root development, carbon discrimination ($\Delta^{13}C$), photosynthesis, radiation use efficiency, water use efficiency, nutrient acquisition/uptake efficiency, phenology / elasticity of development, and vigor (Serraj et al. 2004a).

2.6 Physiological Approaches for Yield Improvement

Analytically, grain yield (YLD) under drought environment can be described by the following expression (Passioura 1977; Fischer 1981):

YLD= Transpiration (T) x Transpiration Efficiency (TE) x Harvest Index (HI)

Thus, improvement in any one or the combinations of the above components is expected to improve grain yield under drought. Improvement in harvest index, the third component in the above expression, is believed to be relatively less cumbersome and therefore can be dealt with at the last stage of breeding and selection. Hence, improvement efforts for the components transpiration and transpiration efficiency need to be attended on a priority basis. Among these three components, genetic enhancement of TE has been taken up as a major research effort in crop improvement programs throughout the world (Bindu-Madhava et al. 2003). As improvement of TE means maximization of crop production per unit of water use, it is one of the important components for improving the drought resistance (Turner et al. 2001).

Although TE is considered a highly useful trait, it was also categorized as a difficult one to screen. Therefore, it becomes necessary to identify surrogate traits that are closely associated with TE for rapid screening of a large number of genotypes. The growing need to find non destructive and less laborious methods of selection for improved TE, has subsequently led to the identification of surrogate traits that are closely related to TE such as carbon isotope discrimination ($\Delta^{13}C$), specific leaf area (SLA), SPAD chlorophyll meter readings (SCMR) and specific leaf nitrogen (SLN) (Hubick et al. 1986; Farquhar et al. 1988; Wright et al. 1994; Nageswara Rao et al. 2001; Bindu-Madhava et al. 2003)

2.6.1 Carbon isotope discrimination ($\Delta^{13}C$)

The method proposed by Farquhar et al. (1982) for estimating TE through measuring the carbon isotope discrimination ($\Delta^{13}C$) in leaves of plants and should be correlated with TE through independent links with the ratio of internal CO_2 pressure to ambient CO_2 pressure (p_i/p_a). The measurement of $\Delta^{13}C$ therefore provides an integrated measure of p_i/p_a, and hence TE, over the life of the plant and has raised the possibility of using $\Delta^{13}C$ as a rapid and nondestructive selection trait in large-scale breeding programs (Farquhar and Richards 1984). The extent of genotypic variation in TE and its correlation with $\Delta^{13}C$ has been determined in an ever-expanding list of grain legume crops, including chickpea (Uday Kumar et al. 1996; Kashiwagi et al. 2006c), bean (Wright and Redden 1995), cowpea (Ismail et al. 1994), peanut (Hubick et al. 1986; Wright et al. 1994), lentil (Matus et al. 1995), and soybean (Uday Kumar et al. 1996). A negative correlation between TE and $\Delta^{13}C$ has been observed in all species. This gave scope for using $\Delta^{13}C$ as an indirect screening tool for TE. But the facilities for $\Delta^{13}C$ analysis are not available everywhere, and it is expensive to analyze large numbers of germplasm and segregating populations, particularly in developing countries. As measurement of $\Delta^{13}C$ requires the use of expensive equipment, SLA, which is a crude but easily measurable parameter, is suggested as a rapid and inexpensive selection criterion for high WUE (Wright et al. 1994; Nageswara Rao and Wright 1994). Further Nageswara Rao et al. (2001) have recently shown that a hand-held portable SPAD chlorophyll meter can be used effectively following necessary protocols for rapid assessment of SLA and specific leaf nitrogen (SLN), the surrogate measure of WUE. This would facilitate screening of large number of segregation populations with ease.

2.6.2 Specific leaf area (SLA)

Specific leaf area (SLA) is the ratio of leaf area to leaf dry weight. Thicker leaves (low SLA) usually have higher chlorophyll per unit leaf area and hence have a greater photosynthetic capacity compared with thinner leaves. The existence of a strong association between SLA and $\Delta^{13}C$ as well as TE and a low genotype by environment interaction for the relationship between SLA and TE have led to the suggestion of SLA as an economical surrogate tool to select for TE (Wright et al. 1994). Also the subsequent findings of low SLA genotypes having greater photosynthetic capacity for unit leaf area further strengthened the suggestion of using leaf thickness (low SLA) as a selection criterion for enhancing TE in groundnut (Nageswara Rao et al. 1995). Although SLA can be measured easily and cost effectively, and can be used as a surrogate for WUE, it is significantly influenced by factors such as time of sampling and leaf age (Wright and Hammer 1994; Nageswara Rao et al. 1995). Moreover, significant and high correlations between SLA and specific leaf nitrogen (SLN) (Nageswara Rao and Wright 1994) and SLA and ribulose 1-5 bisphosphate carboxylase (Rubisco) (Nageswara Rao et al. 1995) in independent studies suggested that photosynthetic capacity per unit leaf area is the major factor contributing to variation in WUE in peanut.

2.6.3 SPAD chlorophyll meter reading (SCMR)

Leaf chlorophyll content is a key indicator of the physiological status of a plant. Chlorophyll content per unit leaf area (chlorophyll density) has been used as an index of photosynthetic capacity and growth of many crop plants and it is most important to crop performance because chlorophyll is a major photosynthetic pigment. The major role of this pigment is to absorb and reacts with visible light in the photosynthesis (Bowyer and Leegood 1997). The ability to maintain high chlorophyll density under water deficit conditions has been suggested as a drought tolerance in barley (This et al. 2000) and potato (Van der Mescht et al. 1999). In peanut, Arunyanark et al. (2008) demonstrated that the variation in TE was closely correlated with genotypic variation in chlorophyll density and hence with photosynthetic capacity, such that chlorophyll density could be used as a potential indicator of TE in peanut.

The chlorophyll meter (SPAD-502 Minolta, Tokyo, Japan), also known as SPAD (soil plant analysis development) meter, can quickly and reliably assess the N status of a crop based on leaf area. In addition, a SPAD chlorophyll meter reading (SCMR) is an indicator of the photo-synthetically active light-transmittance characteristics of the leaf, which is dependent on the unit amount of chlorophyll per unit leaf area (chlorophyll density) (Richardson et al. 2002). Significant and positive correlations between SCMR and chlorophyll content, and chlorophyll densities have been reported (Akkasaeng et al. 2003; Arunyanark et al. 2008). Nageswara Rao et al. (2001) reported significant and high interrelationship among SLA, SLN, and SCMR. A direct close relationship of TE with SPAD chlorophyll meter readings (SCMR) was reported in groundnut (Nageswara Rao et al. 2001; Bindu-Madhava et al. 2003) and SCMR is a direct linear relationship through extracted leaf chlorophyll (Yadava 1986) and also related leaf nitrogen concentration (Kantety et al. 1996; Bullock and Anderson 1998). Nageswara Rao et al. (2001) and Bindu-Madhava et al. (2003) suggested that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA or high SLN (and hence high WUE) in peanut.

The SCMR is known to be related to leaf N content in several crops (Schepers et al. 1992; Uzik and Zofajova 2000; Veeraputhiran et al. 2001). Nageswara Rao et al. (1995) reported that leaf N content has a direct relationship with the amount of ribulose1, 5 biposphate carboxylase, which accounts for 37% of the soluble proteins and thus with the photosynthesis. The most of the variation in the WUE and Δ^{13}C in groundnut was associated with the variation in Rubisco and the variation in WUE (TE) is associated with variation in photosynthetic capacity per unit leaf area because thicker leaves usually have a higher density of chlorophyll per unit leaf area and hence have a greater photosynthetic capacity compared with thinner leaves (Wright et al. 1994; Nageswara Rao et al. 1995). Higher SCMR seems to be an indication of the genotype's capacity for higher carbon assimilation and in turn seed yields even under moisture limited conditions. It could be hypothesized that peanut genotypes with high SCMR and low SLA have more photosynthetic machinery per unit leaf area and hence potential for greater assimilation under drought stress.

Recent studies indicated that SCMR and SLA which are easy to measure and are highly correlated with TE. The relationship between TE and SCMR is positive and between TE and SLA is negative. SCMR and SLA are negatively correlated and genetic variation for SCMR has also been reported in chickpea (Nageswara Rao et al. 2001; Upadhyaya 2005; Kashiwagi et al. 2006b). As a noninvasive surrogate of TE, SCMR is easy to operate, reliable, fairly stable and low cost. The SCMR is reported to be more stable than SLA. A significant positive relationship was observed between seed yield and SCMR in many crops; black gram, green gram, groundnut, cereals and maize (Argenta et al. 2001; Costa et al. 2001; Nageswara Rao et al. 2001; Sudhakar et al. 2006). The advantages such as easy and rapid measurement, nondestructive method and light weight made SPAD meters the best choice for use in the trait-based breeding program to improve the drought tolerance of groundnut and chickpea at the International Crops Research Institute for the Semi- Arid Tropics (ICRISAT) (Serraj et al. 2004b; Kashiwagi et al. 2006b). However, they stated that it is difficult to complete SCMR observations in a large-scale breeding programme within a specified time and crop stage.

2.6.4 Leaf relative water content (RWC)

Leaf relative water content (RWC) is one of the several methods to measure tissue water status (Sinclail and Ludlow 1985).The RWC represents a useful indicator of the state of water balance of a plant, essentially because it expresses the absolute amount of water, which the plant requires to reach artificial full saturation (González and González-Vilar 2001).The method is simple and estimates the current water content of the sampled leaf tissue relative the maximal water content it can hold at full turgidity. It is a measure of water deficit in the leaf. Normal values of RWC range between 98% in turgid and transpiring leaves to about 40% in severely desiccated and dying leaves. In most crop species the typical RWC at about wilting is around 60% to 70%, with exceptions. Small discs or tissue pieces are used to determine a great variety of physiological processes in plants, although it should be taken in account the possible heterogeneity of the leaf and canopy to obtain a good correlation between RWC and some physiological processes (Barr and Weatherley 1962).

Leaf relative water content is closely related to leaf water potential. Sometimes, relationship between leaf water potential and RWC of leaves is used for evaluate water deficit magnitude in the plant tissues and cells and predicting tissues resistant to desiccation resulted from water deficit (Ferrat and Lovatt 1999; Khan et al. 2007). It seems that tissues, which able to maintain higher RWC with decreasing water potential are more resistant to drought conditions and desiccation resulted from this stress (Schonfeld et al. 1988; Irigoyen et al. 1992; Ferrat and Lovatt 1999). Saneoka et al. (2004) reported that RWC in lentil genotypes under drought stress is lower than non stress conditions. Costa-Fraca et al. (2000) indicated that the RWC of bean (*Vicia faba* L.) leaf decreased due to drought. Drought stress has a significant effect on the decline of leaf RWC and membrane rigidity (Sairam and Srivastava 2001). In an experiment on chickpea and beans, it was revealed that water deficit stunted the growth of both crops, which in turn affect their yields and decreased leaf and root water potential (Grzesiak et al. 1997).

Plant water status, measured as leaf water potential, leaf rolling or drying score or leaf relative water content (RWC), can differ significantly among cultivars exposed to the same period of water exclusion (O'Toole and Moya 1978). In rice, these differences are related to variation in stomatal control of transpiration, water extraction and variation in canopy size at the onset of stress (Dingkuhn et al. 1989; Lilley and Fukai 1994; Mitchell et al. 1998). In cowpea studied under mid-season drought, the high RWC of leaves was maintained in some of the genotypes by stomata closure and a reduction of leaf area. Drought avoidance by maintaining high leaf water content was negatively associated with SLA (Anyia and Herzog 2004). Jongrungklang et al. (2008) found that the more severe the drought stresses the more was the increase in the SCMR. In fact, plant water status is related to level of soil moisture. In rice under drought stress conditions the correlation between SCMR with RWC was positive and significant and SCMR decreased with drought stress compared to control. Hence, RWC is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit (Pirdashti et al. 2009).

CHAPTER III

EVALUATION OF DROUGHT TOLERANCE OF CHICKPEA (*Cicer arietinum* L.) UNDER NON-IRRIGATED CONDITION

3.1 Introduction

In today's world, the nutrition problem is growing increasingly, paralleling to population growth. The production of high-range protein foods has been important for solving the nutrition problem, on a particular level. For this reason, growing the most productive and high-quality varieties to the regions is paramount. Chickpea plays an important role in human nutrition as a source of protein, energy, fiber, vitamins and minerals for large population sectors in the developing world and is considered a healthy food in many developed countries. Chickpea contains on the average 22% protein, 4.5% fat, 63% carbohydrate, 8.0% crude fibre and 2.7% ash (Miao et al. 2009).

Chickpea growing season is terminated by drought stress associated with rising temperatures and evapotranspiration and a lack of rainfall. Yield losses due to terminal drought estimates range from 35 to 50% across the Semi-Arid Tropic (SAT) and West Asia and North Africa (WANA) (Sabaghpour 2003). Yield reduction differed in the range 30 to 60 percent in chickpea, which depended on geographical region and length of crop season (Saxena et al. 1993b).

The most important step towards maximizing yield of chickpea is to ensure that the phenology of the crop or cultivar is well matched to resources and constraints of the production environment. In order to increase the productivity of chickpea under drought stress, improved adaptation is required. Chickpea genotypes that are tolerant / resistant to drought have been reported (Saxena et al. 1993b; Bejiga and Anbessa 1994; Johansen et al. 1994).

Yield and yield components analysis provides a framework for identifying potentially useful traits for yield improvement. Traditionally, plant breeders have optimized yield largely by empirical selection with little regard for the physiological processes involved in yield formation. Selection of high yielding cultivars via specific traits requires knowledge not only of final yield but also of the many compensation mechanisms among yield components resulting from changing genotypic, environmental and management factors (Rosalind et al. 2001). Selection for high growth vigor enhances chance for escaping terminal drought stress. Chickpea genotypes with high growth vigor are early maturity. Initial growth vigor is suitable character for large-scale evaluation of germplasm and breeding materials (Sabaghpour et al. 2003). Therefore, the objective of this study was to evaluate the high yielding chickpea genotypes adaptable to drought-prone environment during raining seasons.

3.2 Materials and Methods

3.2.1 Experimental site, design and plant materials

The experiment was conducted at Sebin Research Farm (20° 25´ N; 96° 09´ E; altitude 230 m), Yamethin Township, Mandalay Division during post-monsoon season, 2008-2009 as a preliminary yield evaluation of chickpea genotypes. The soil of Sebin Research Farm was a clay-loam with low in organic matter (1.2 %), phosphorus (1.615 kg ha^{-1}) and potassium (8.16 kg ha^{-1}) and moderately alkaline reaction (pH 7.6).The experiment was laid out in a Randomized Complete Block Design with 3 replications.

The experimental materials consisted of 39 genotypes of chickpea (Table 3.1). Thirty one genotypes were supported by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and 8 genotypes were developed at Department of Agricultural Research (DAR) from the national breeding programmes of chickpea. In this study, Yezin 3 and Yezin 4 which have been widely grown in Myanmar for more than 15 years were included. The genotype, ICC 4958 was used as drought tolerant check which is recommended by ICRISAT. It has multiple traits of large root for extraction of water and a rapid rate of seed development related to its large seed size (Serraj et al. 2003).

3.2.2 Weather condition

The experimental site is characterized by low annual rainfall of 10 years average (850.9 mm) with uneven rainfall distribution and wide variation from year to year. The total precipitation during the growing season (2008-2009) was 806.5 mm. The monthly average temperature for 2008-2009 was approximately the same with the long-term mean. Mean temperature was found to be ranged from 11.2°C to 35.7°C during crop season (Appendix 1). There was a 12.7 mm rainfall which occurred at 20th March 2009 (at harvest time).

Table 3.1. List of tested plant materials, types and seed source

Sr.No.	Genotypes	Type	Source
1	Annigeri	Desi	ICRISAT
2	ICCC37	Desi	ICRISAT
3	ICCV 00108	Desi	ICRISAT
4	ICCV 00401	Kabuli	ICRISAT
5	ICCV 01303	Kabuli	ICRISAT
6	ICCV 03103	Desi	ICRISAT
7	ICCV 03107	Desi	ICRISAT
8	ICCV 03110	Desi	ICRISAT
9	ICCV 03111	Desi	ICRISAT
10	ICCV 03203	Desi	ICRISAT
11	ICCV 03302	Kabuli	ICRISAT
12	ICCV 03403	Kabuli	ICRISAT
13	ICCV 03406	Kabuli	ICRISAT
14	ICCV 03407	Kabuli	ICRISAT
15	ICCV 04103	Desi	ICRISAT
16	ICCV 04110	Desi	ICRISAT
17	ICCV 04111	Desi	ICRISAT
18	ICCV 04301	Kabuli	ICRISAT
19	ICCV 04303	Kabuli	ICRISAT
20	ICCV 04304	Kabuli	ICRISAT
21	ICCV04306	Kabuli	ICRISAT
22	ICCV 95311	Kabuli	ICRISAT
23	ICCV 97024	Desi	ICRISAT
24	ICCV 97306	Kabuli	ICRISAT
25	ICCV 97314	Kabuli	ICRISAT
26	Karachi	Desi	ICRISAT
27	PCHL 04-2	Desi	Myanmar
28	PCHL 04-32	Kabuli	Myanmar
29	PCHL 04-34	Kabuli	Myanmar
30	PCHL 04-5	Desi	Myanmar
31	Shwenilonegi	Desi	Myanmar
32	Yezin 3 (ICCV 2)	Kabuli	ICRISAT
33	Yezin 4 (ICCV 88202)	Desi	ICRISAT
34	Yezin 5 (ICCV 3)	Kabuli	ICRISAT
35	Yezin 6 (ICCV 92944)	Desi	ICRISAT
36	ZCHL 05-2	Desi	Myanmar
37	ZCHL 05-20	Desi	Myanmar
38	ZCHL 05-73	Kabuli	Myanmar
39	ICC 4958 (Check)	Desi	ICRISAT

3.2.3 Crop management

The crop was grown under non-irrigated condition as it is normally grown with residual soil moisture from the preceding monsoon. The crop was grown on 23rd December 2008 and harvested on 25th March 2009. Each genotype was sown in double row of 5 m length with a spacing of 30 and 10 cm between and within the rows, respectively. The recommended practice of Sebin Research Farm was adopted for raising the crop.

3.2.4 Data collection

Data were taken from 5 sample plants randomly selected from each plot. Days to 50% flowering, days to maturity, canopy height, canopy width, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod and 100-seed weight were recorded during the cropping season (IBPGR 1993). Plot yield was taken from 5 m x 0.6 m for estimating seed yield per hectare.

3.2.5 Statistical analysis

The collected data were subjected to analysis of variance and means were separated according to the Least Significant Difference (LSD) at 5% level. Simple correlation coefficients between characters were also carried out by using GenStat (version 12.1) program. Heritability estimates in broad sense were calculated with the following relationship (Singh et al. 1993):

$$h^2 = \frac{\delta^2_g}{\delta^2_g + \delta^2_e}$$

Where,

$\delta^2_e = M_e$

$\delta^2_g = (M_g - M_e)/b$

δ^2_e = Environmental variance

M_e = Mean square of error

δ^2_g = Genotypic variance

M_g = Mean square of genotype

b= Replication

3.3. Results and Discussion

3.3.1 Yield and yield contributing characters

Significant differences were observed for all the characters studied among the tested genotypes (Table 3.2). Among these characters large amount of variance had been recorded for seed yield. Considerable differences in variances were also recorded the minimum and maximum values of 856 to 2226 kg ha^{-1}, 24 to 53, 14.0 to 43.7 g, 22.6 to 40.2 cm for seed yield, number of pods per plant, 100-seed weight and canopy height. In the present study, the value of heritability estimates revealed that canopy height, seeds per pod, 100-seed weight and seed yield exhibited high heritability values. This indicates that these characters are less influenced by environmental fluctuations.

The overall mean for days to 50% flowering was 47 days with the earliest genotype ZCHL 05-73 flowering in (42 days) followed by Yezin 3 and Yezin 4 flowering in (44 days) (Table 3.3). Yezin 3 (ICCV 2) is currently the world's shortest duration of kabuli type which is able to grow fast on the conserved receding soil moisture, and mature before the moisture depletion from the deeper soil layers (Serraj et al. 2003). Such extra earliness may be exploited in the improvement of chickpea for short growing environment, such that flowering and pod setting of the crop occur before water stress becomes a serious limiting factor. However, being an extra-short duration variety, ICCV 2 has a limited yield potential, lower than the traditional desi types (Kumar and Rheenen 2000).

Days to maturity of tested genotypes ranged from 86 days in ICCV 97314 to 94 days in ICC 4958 (Table 3.3). The difference between the earliest and the latest maturing genotypes was 8 days. Generally, days to maturity of tested genotypes were less than that of check genotypes, ICC 4958, and sixteen genotypes matured significant earlier than ICC 4958. Growth duration determines water requirement and the probability of exposure to stress, both of which decrease in early flowering genotypes (Blum 1996). For most crop species, breeding for shorter duration is a major objective, not only to match phenology to season length but also to fit crop into more intensive crop rotations.

In the present study, canopy height ranged from 22.6 cm for Yezin 3 to 40.2 cm for ICCV 04103 (Table 3.3). Among genotypes, ICCV 04103 had exhibited the maximum canopy height followed by ICCV 03407 (39.5 cm), which were significantly taller than ICC 4958 (34.1 cm). In contrast, canopy height of Yezin 3

Table 3.2. Mean, standard error, range, significant level, coefficient of variation (CV %) and heritability of traits for chickpea genotypes at Sebin Research Farm during post-monsoon season, 2008-2009

Traits	Mean ± SE	Range	Significant level	CV (%)	Heritability *(h^2)*
Days to 50% flowering	47.3±1.4	42-51	***	5.2	0.37
Days to maturity	90.6±1.2	86-94	**	2.4	0.26
Canopy height (cm)	31.3±1.4	22.6-40.2	***	7.7	0.74
Canopy width (cm)	48.7±2.7	39.3-56.0	**	9.8	0.28
Primary branches per plant	3.9±0.6	2-6	**	28.6	0.29
Secondary branches per plant	5.1±1.2	2-9	*	39.3	0.16
Pods per plant	34.6±4.4	24-53	***	22.0	0.34
Seeds per pod	1.2±0.7	1.0-1.6	***	10.6	0.62
100-seed weight (g)	29.1±1.2	14.0-43.7	***	6.9	0.94
Seed yield (kg ha^{-1})	1664±127	856-2226	***	13.3	0.58

*, **, *** Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

was minimum (22.6 cm) and was not significantly different with Yezin 5 (24.1 cm), ICCV 03110 (24.9 cm), ICCV 04110 (25.1 cm), ICCV 97024 (25.2 cm), Annigeri (25.4) and ZCHL 05-73 (26.4cm).

Canopy width of tested genotypes was significantly different ($p < 0.01$) (Table 3.2). Among them PCHL 04-2 was observed to be the widest (55.9 cm) compared to all the tested genotypes (Table 3.3). In this study, the large numbers of genotypes were similar with ICC 4958 (47.1 cm). The PCHL 04-32 was found to be the lowest canopy width (39.3 cm) among the tested genotypes.

The number of primary branches per plant was significantly different ($p < 0.01$) among the tested genotypes (Table 3.2). However, large numbers of genotype showed not significantly in primary branches with that of ICC 4958 (4). Maximum number of primary branches per plant was recorded in ZCHL 05-73 (5.9) and the minimum was observed in ICCV 04304 (2.1) (Table 3.3). However, there were 10 chickpea genotypes produced significantly higher number of secondary branches per plant (6.2 to 8.7) than ICC 4958 (3.4). The highest being recorded in Karachi (8.7) followed by Annigeri and ICCV 00401 (7.7). In contrast 2 genotypes produced fewer secondary branches per plant and the lowest (2.5) was recorded in ZCHL 05-73. High variability in the number of secondary branches of chickpea genotypes was also reported by Ahmad et al. (2003).

Number of pods per plant, the most important yield contributor had shown significant differences among genotypes ($p < 0.001$). Karachi produced the maximum number of pods per plant (53) followed by ICCV 97024, ICCV 95311, and ICCV 00108 with (46 pods) (Table 3.3). ZCHL 05-73 produced minimum number of pods (24) which was significantly lower than that of ICC 4958 (37).

Number of seeds per pod was significantly different ($p < 0.001$) among the tested genotypes (Table 3.2). The PCHL 04-5 showed the highest number of seeds per pod (1.6) followed by ICCV 03111, Yezin 4, ZCHL 05-2 and ICCV 04111 with (1.5). The lowest value (1.0) was recorded in PCHL 04-32 and ICC 4958. Significant variability in seeds per pod in chickpea was also observed by Ahmad et al. (2003).

The weight of 100 seed varied significantly from 14.0 to 43.7 g (Table 3.3). This result showed a wide range of variability among the genotypes. There were 7 genotypes which had larger seed size (38.5 to 43.7 g) than ICC 4958 (34.4 g). In this study, large number of genotypes showed smaller seed size than ICC 4958. Among these genotypes, Karachi was recorded the least in 100-seed weight (14.0 g).

Table 3.3. Performances of chickpea genotypes under non-irrigated condition at Sebin Research Farm during post-monsoon season, 2008-2009

Genotypes	Days to 50% flowering	Days to maturity	Canopy height (cm)	Canopy width (cm)	Primary branches per plant
Annigeri	49	92	25.4	48.9	4
ICCC 37	48	92	26.7	46.9	3
ICCV 00108	49	92	31.3	49.8	4
ICCV 00401	49	93	36.3	53.4	2
ICCV 01303	45	89	31.3	52.5	3
ICCV 03103	48	92	29.7	52.4	4
ICCV 03107	50	91	33.7	51.7	6
ICCV 03110	50	91	24.9	45.2	3
ICCV 03111	46	89	29.0	53.3	4
ICCV 03203	51	90	33.9	50.8	3
ICCV 03302	46	89	29.1	44.4	4
ICCV 03403	50	92	35.1	53.5	3
ICCV 03406	47	91	36.4	44.8	4
ICCV 03407	44	88	39.5	46.9	4
ICCV 04103	45	90	40.2	52.6	4
ICCV 04110	50	92	25.1	45.9	3
ICCV 04111	48	93	33.7	49.8	4
ICCV 04301	47	91	35.2	43.1	3
ICCV 04303	48	91	33.6	48.4	3
ICCV 04304	50	91	37.1	51.2	2
ICCV 04306	47	90	35.1	49.3	3
ICCV 95311	46	92	30.7	51.3	4
ICCV 97024	49	91	25.2	48.7	5
ICCV 97306	45	91	30.1	48.4	5
ICCV 97314	45	86	31.0	42.6	5
Karachi	50	94	30.1	54.5	4
PCHL 04-2	48	90	32.4	56.0	5
PCHL 04-32	45	89	27.4	39.3	3
PCHL 04-34	47	90	28.0	41.3	2
PCHL 04-5	45	90	34.4	52.4	3
Shwenilonegi	47	91	33.0	52.0	4
Yezin 3	44	88	22.6	45.0	3
Yezin 4	44	89	29.1	45.3	6
Yezin 5	46	91	24.1	44.6	5
Yezin 6	45	90	33.8	47.5	5
ZCHL 05-2	51	92	34.0	53.6	3
ZCHL 05-20	47	91	31.2	52.6	3
ZCHL 05-73	42	87	26.4	43.3	6
ICC 4958 (C)	51	94	34.1	47.1	4
Mean	47	91	31.3	48.7	4
$LSD_{(0.05)}$	4.0	3.5	3.9	7.8	1.8

Table 3.3 (Contd.). Performances of chickpea genotypes under non-irrigated condition at Sebin Research Farm during post-monsoon season, 2008-2009

Genotypes	Secondary branches per plant	Pods per plant	Seeds per pod	100-seed weight (g)	Seed yield (kg ha^{-1})
Annigeri	8	34	1.1	23.2	1612
ICCC 37	8	39	1.3	19.3	2181
ICCV 00108	4	46	1.4	24.5	2226
ICCV 00401	8	30	1.1	36.6	1735
ICCV 01303	4	32	1.1	35.8	856
ICCV 03103	4	43	1.3	26.9	1973
ICCV 03107	6	43	1.4	19.4	2055
ICCV 03110	7	35	1.2	20.0	1664
ICCV 03111	4	32	1.6	26.3	1539
ICCV 03203	6	40	1.4	24.3	2000
ICCV 03302	4	26	1.0	33.3	1590
ICCV 03403	5	28	1.1	40.9	1720
ICCV 03406	4	33	1.1	38.6	1767
ICCV 03407	5	25	1.1	43.7	1495
ICCV 04103	5	29	1.4	24.8	1425
ICCV 04110	6	33	1.1	20.7	1775
ICCV 04111	3	32	1.5	28.0	1357
ICCV 04301	5	33	1.2	42.6	1547
ICCV 04303	5	28	1.1	41.8	1594
ICCV 04304	5	24	1.3	36.0	1708
ICCV 04306	4	28	1.2	41.9	1393
ICCV 95311	4	46	1.0	33.0	1873
ICCV 97024	7	46	1.3	17.6	952
ICCV 97306	5	37	1.1	38.5	1641
ICCV 97314	4	29	1.1	33.3	1711
Karachi	9	53	1.4	14.0	1594
PCHL 04-2	7	36	1.1	32.7	1914
PCHL 04-32	6	41	1.0	31.1	1972
PCHL 04-34	6	40	1.1	30.8	1795
PCHL 04-5	4	29	1.6	21.6	1598
Shwenilonegi	4	36	1.1	36.2	1757
Yezin 3	4	26	1.1	24.2	1331
Yezin 4	5	37	1.5	19.0	1468
Yezin 5	5	30	1.1	26.9	1595
Yezin 6	5	43	1.1	25.5	2016
ZCHL 05-2	5	32	1.5	22.9	1709
ZCHL 05-20	3	33	1.0	25.2	1781
ZCHL 05-73	3	24	1.4	18.1	1178
ICC 4958(C)	3	37	1.0	34.4	1786
Mean	5	35	1.2	29.1	1664
$LSD_{(0.05)}$	3.3	12.4	0.2	3.3	359

Seed yield ranged from 856 kg ha^{-1} in ICCV 01303 to 2226 kg ha^{-1} in ICCV 00108, and the differences for seed yield among genotypes was significant ($p < 0.001$). The high yield were observed on ICCV 00108, ICCC 37, ICCV 03107 and Yezin 6 ranges from 2016 to 2226 kg ha^{-1}, whereas the drought tolerant checked genotype ICC 4958 gave 1785 kg ha^{-1} (Table 3.3). The higher yield of these four genotypes was due to the production of higher number of pods per plant which was supported by the greater number of secondary branches per plant. The result of present study was in agreement with the results of Islam et al. (2008).

In this study, large number of genotypes yielded not significantly with that of ICC 4958. However, there were 7 genotypes which showed significantly lower in seed yield than ICC 4958 (Table 3.3). Islam et al. (2008) reported that low yielding genotypes also produced lower number of secondary branches per plant. Although Karachi and ICCV 97024 were recorded with a highest number of pods per plant and secondary branches per plant, these two genotypes produced low yield. It might be due to the lowest seed size of these genotypes. Similar findings have been reported by Islam et al. (2008). The variation in yield components and seed yield among the chickpea genotypes were also reported by Chandra and Yadav (1997).

3.3.2 Correlation between seed yield and yield attributes

The associations of different yield attributes with seed yield have been determined (Table 3.4). There was a significant and positive correlation of seed yield with number of pods per plant ($r=0.41$ at $p < 0.01$) and days to 50% flowering ($r=0.39$ at $p < 0.01$). Similarly, Khan and Qureshi (2001) have reported that number of pods per plant is positively correlated with seed yield in chickpea. Also, Guler et al. (2001) informed that the direct effect of the number of pods per plant on seed yield in chickpea was significant. Moreover, number of pods per plant was positively correlated with days to 50% flowering, days to maturity and secondary branches per plant. Those results indicated that prolong reproductive phase in such environment may lead to increase in yield. Islam et al. (2008) reported that high yielding genotypes of chickpea, in general, produced higher number of secondary branches per plant. It means that yield is positively correlated with secondary branches. Ali et al. (1999) indicated the importance of secondary branches and pods per plant in determining the yield of chickpea.

Table 3.4. Correlation coefficients among yield attribute and yield at Sebin Research Farm during post-monsoon season, 2008-2009

Traits	Days to 50% flowering	Days to maturity	Canopy height (cm)	Canopy width (cm)	Primary branches per plant	Secondary branches per plant	Pods per plant	Seeds per pod	100-seed weight (g)	Seed yield (kg ha^{-1})
50%F	-									
Maturity	0.70***	-								
CaH	0.08	-0.06	-							
CaW	0.36*	0.40*	0.41*	-						
PB	-0.33*	-0.37*	-0.17	-0.11	-					
SB	0.46**	0.38*	-0.19	0.11	-0.13	-				
Pod	0.34*	0.40*	-0.21	0.13	0.10	0.43**	-			
Seed	0.08	0.04	0.10	0.33*	0.11	-0.06	0.12	-		
100 seed wt.	-0.12	-0.18	0.53***	-0.06	-0.27	-0.26	-0.41**	-0.56***	-	
Seed yield	0.39*	0.29	0.10	0.04	-0.15	0.21	0.41**	-0.07	-0.04	-

*, **, *** Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

50%F= Days to 50% flowering, Maturity= Days to maturity, CaH=Canopy height (cm), CaW= Canopy width (cm), PB= Primary branches per plant, SB= Secondary branches per plant, Pod= Pods per plant, Seed= Seeds per pod, 100-seed wt. =100-seed weight (g), Seed yield= Seed yield (kg ha^{-1})

Results of the present study indicated that the100-seed weight was negatively correlated with number of pods per plant and number of seeds per pod. Those results were in close agreement with Hassan et al. (2005) and Talebi et al. (2007). In the present study, no correlation was found between seed yield and canopy height and canopy width. Similarly, Khosh-Khui and Niknejad (1972) reported that there was no association between plant width and seed yield. In contrast, Mishra et al. (1988) stated that grain yield in chickpea had positive association with plant spread, primary branches per plant and number of pods per plant. This contrary might be due to the different genotypes used in their studies.

3.4 Conclusion

In summary, genotypes such as ICCV 00108, ICCC 37, ICCV 03107 and Yezin 6 were superior in respect of seed yield compared to other genotypes. Understanding relationships among chickpea yield and yield components is critical in developing desirable genotypes. Results showed that the number of pods per plant was positively and significantly correlated with seed yield. Therefore, for selection programs to improve seed yield of chickpea under residual moisture condition, number of pods per plant could be used as a selection index. The implication of the results of this study may be possible for development of chickpea in drought tolerance. It is emphasized that breeding strategies must seek to develop genotypes with a greater degree of adaptability to drought conditions. Based on this experiment, the physiological basis for drought tolerance is needed to confirm on these chickpea genotypes for further investigations.

CHAPTER IV

EVALUATION OF DROUGHT TOLERANT CHICKPEA (*Cicer arietinum* L.) GENOTYPES WITH DROUGHT TOLERANCE INDICES

4.1 Introduction

Drought is usually the most important abiotic stress that affects crop production. Hence, selection for drought resistance and production of tolerant cultivars with high yield potential is the main objective of breeding programmes. Many researchers believed that tolerance to drought stress must be done via genetic improvement of seed yield in crops (Passioura 1996). It is known that chickpea thrives well under dry condition. However, breeding for resistance or tolerance to drought stresses in chickpea is limited by the lack of adequate selection criteria for stress tolerance. Most breeding programs are based on visual scoring in the controlled or field conditions.

Attempts to measure the degree of tolerance with a single parameter have limited value because of the multiplicity of the factors and their interactions contributing to drought tolerance under field conditions. Different workers used different methods to evaluate genetic differences in drought tolerance (Bidinger et al. 1982). To evaluate response of plant genotypes to drought stress, some selection indices based on a mathematical relation between stress and optimum conditions has been proposed (Rosielle and Hamblin 1981; Clarke et al. 1992; Fernandez 1992; Sio-Se Mardeh et al. 2006). Abebe et al. (1998) compared yield-based selection indices for identifying high-yielding dry bean lines under drought and optimum conditions.

The high yielding capacity and mean productivity (MP) of genotypes can be explained as tolerant to drought stress (Toker and Cagirgan 1998). Fischer and Maurer (1978) developed a drought susceptibility index (DSI) based on the ratio of yield of individual genotypes under stress and non-stress conditions to the ratio of genotype means across stress and non-stress conditions. This index has been widely used in identifying genotypes adapted to stress (Bruckner and Frohberg 1987; Ceccarelli 1987; Clarke et al. 1992; Abebe et al.1998).

Moghaddam and Hadi-Zadeh (2002) found that Stress Tolerance Index (STI) was more useful in order to select favorable corn cultivars under stressful and stress-free conditions. Khalili et al. (2004) showed that based on Geometric Mean Productivity (GMP) and STI indices, corn yield hybrids with high yield in both stress and non-stress environments can be selected. In safflower, Purdad (2004) reported the efficiency of GMP and STI indices in identifying and selection of drought resistant. Arslan (2007) and Ashkani et al. (2007) also introduced STI and GMP indices as the best criteria in screening of the resistant cultivars. Deshmukh et al. (2004) evaluated chickpea genotypes for drought tolerance by using Drought Tolerance Efficiency (DTE). The objective of this study was to evaluate the appropriate drought tolerant genotypes with the drought tolerance indices and to study correlation among drought tolerance indices.

4.2 Materials and Methods

4.2.1 Experimental site, design and plant materials

Chickpea was mainly grown in Sagaing Division which contributed to 49% of total chickpea production. Therefore, the experiment was carried out at Zaloke Research Farm (22.2° N; 95° E; altitude 74 m), Monywa Township, Sagaing Division in post-monsoon season, 2009-2010. The soil of the experiment was sandy loam with slightly alkaline reaction (pH 8.81). Organic matter content of these soils is very low (0.65%). Available nitrogen (56 ppm) and potassium (90 ppm) are low, and available phosphorus (17 ppm) is medium. The weather conditions of experimental site during growing period are shown in Appendix 2.

This study was conducted under non-irrigated and irrigated conditions in two sets of Randomized Complete Block design with three replications. Thirty-nine chickpea genotypes were tested and have been described in detail in Table 3.1.

4.2.2 Crop management

Pre-sowing irrigation was given to non-irrigated treatment for good germination. In addition to pre-sowing irrigation, additional two irrigations were given at 40 and 60 days after sowing (DAS) for irrigated treatment. The experiment was grown on 17th November 2009 and harvested on 7th March 2010. Plot size was 5 m x 0.6 m with the row to row and plant to plant spacing of 30 cm and 10 cm. The recommended package of practices of this Research Farm was followed for raising the crop.

4.2.3 Data collection

The observations on days to maturity, canopy height, number of pods per plant, number of seeds per pod, and 100-seed weight were recorded on 5 randomly selected plants and plot yield was taken from 5 m x 0.6 m for estimating seed yield per hectare. The following drought tolerance indices such as Stress Tolerance Index (STI), Drought Tolerance Efficiency (DTE), Mean Productivity (MP), Geometric Mean Productivity (GMP), Tolerance Index (TOL) and Drought Susceptibility Index (DSI) were computed based on seed yield of non-irrigated and irrigated conditions.

$$\text{STI} = \frac{\text{YI} \times \text{YNI}}{(\text{Mean seed yield of all genotypes under irrigated condition})^2}$$

(Fernandez 1992)

$$\text{DTE (\%)} = \frac{\text{YNI}}{\text{YI}} \times 100$$

(Deshmukh et al. 2004)

$$\text{MP} = \frac{\text{YI} + \text{YNI}}{2}$$

(Toker and Cagirgan 1998).

$$\text{GMP} = (\text{YI} \times \text{YNI})^{0.5}$$

(Fernandez 1992)

$$\text{TOL} = \text{YI} - \text{YNI}$$

(Fernandez 1992)

$$\text{DSI} = \frac{1 - (\text{YNI} / \text{YI})}{\text{D}}$$

(Fischer and Maurer 1978)

Where,

YNI = seed yield of the genotype under non-irrigated condition

YI = seed yield of the genotype under irrigated condition

$$\text{D} = 1 - \frac{\text{Mean seed yield of all genotypes under non-irrigated condition}}{\text{Mean seed yield of all genotypes under irrigated condition}}$$

4.2.4 Statistically analysis

The data were subjected to analysis of variance. Genotypes means were compared by Least Significant Difference (LSD) at 5% level. Simple correlation coefficients between drought tolerance indices and seed yield under two conditions were estimated by using GenStat software (version 12.1).

4.3 Results and Discussion

4.3.1 Seed yield performance

There were significant differences ($p < 0.01$ to $p < 0.001$) among genotypes in respect to yield and yield attributes, which demonstrates high genetic variance among them that enabled to screen drought tolerant genotypes (Table 4.1). Similarly, environments (non-irrigated and irrigated) differed significantly ($p < 0.001$ and $p < 0.01$) for seed yield and biomass yield. Moreover, genotype x environment interaction was also significant which suggested that performance of genotypes was inconsistent across different environmental conditions. This was illustrated by the performance of ICCC 37 and ICCV 00108 (Appendix 3). These two genotypes did not differ significantly under irrigated condition. However, ICCC 37 was significantly better under non-irrigated condition. In the present study, changes in rank and differences in seed yield for several other pairs of genotypes across non-irrigated and irrigated conditions were observed due to significant genotypes x environment interaction.

The seed yield data of individual genotypes showed a great variation under both non-irrigated as well as irrigated condition (Appendix 3). Seed yield of non-irrigated condition ranged between 536 and1195 kg ha^{-1} and of irrigated condition between 730 and 1414 kg ha^{-1}. Mean seed yield under non-irrigated condition was reduced by 21% compared to seed yield under irrigated condition. Similar results has been reported by Deshmukh et al. (2004) who reported that seed yield was reduced by 19.19% in desi and 44.09% in kabuli types under rainfed (non-irrigated) condition. On the basis of seed yield per se, 13 genotypes gave a significantly higher yield than the check, ICC 4958, under non-irrigated condition. Among these high yielding genotypes, PCHL 04-34 gave the highest yield (1195 kg ha^{-1}) followed by ICCC 37 (1109 kg ha^{-1}) and PCHL 04-2 (1102 kg ha^{-1}) (Appendix 3). Under the irrigated condition, six genotypes showed significantly higher yield than ICC 4958. The ICCV 00108 showed the highest seed yield (1414 kg ha^{-1}) followed by Yezin 5 (1308 kg ha^{-1}) and ICCV 95311(1299 kg ha^{-1}). Among these high yielding genotypes,

Table 4.1. Mean square from combined analysis of variance of chickpea genotypes for seed yield and yield attributes under non-irrigated and irrigated conditions at Zaloke Research Farm during post-monsoon season, 2009-2010

Source of variation	df	Seed yield (kg ha^{-1})	Biomass (kg ha^{-1})
Environment (E)	1	4090560***	17914700**
Genotypes (G)	38	166246***	611203***
G x E	38	59187***	361929***
Error	152	7172	30993
Source of variation	**df**	**Harvest index**	**Pods per plant**
Environment (E)	1	0.017	23.4
Genotypes (G)	38	0.005***	109.2***
G x E	38	0.006***	150.6***
Error	152	0.001	13.6
Source of variation	**df**	**Seeds per pod**	**100-seed weight (g)**
Environment (E)	1	0.04	236.1
Genotypes (G)	38	0.11***	172.1**
G x E	38	0.03*	16.7
Error	152	0.02	11.1
Source of variation	**df**	**Canopy height**	**Days to maturity**
Environment (E)	1	59.0	520.5*
Genotypes (G)	38	42.1***	86.1***
G x E	38	27.9**	12.0***
Error	152	13.5	4.2

*, **, *** Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

ICCC 37, ICCV 04110 and ICCV 95311 and PCHL 04-5 gave significantly higher yield than ICC 4958 under both non-irrigated and irrigated conditions.

4.3.2 Drought tolerance indices

The drought tolerance indices such as stress tolerance index (STI), drought tolerance efficiency (DTE), mean productivity (MP), geometric mean productivity (GMP), tolerance to drought stress (TOL) and drought susceptibility index (DSI) were given in Table 4.2. The genotype with higher STI and DTE value was rated as tolerant genotype for moisture stress condition (Fernandez 1992; Deshmukh et al. 2004). Based on the STI, ICCC 37, PCHL 04-34, ICCV 04110, PCHL 04-5 and ICCV 95311 were identified as the top five drought tolerant genotypes (Table 4.2). On the other hand, Shwenilonegi, PCHL 04-34, PCHL 04-2, ICCV 03111, ICCV 04306, ZCHL 05-20 and ICCV 04301 had more than 90% DTE, with a very low yield under irrigated condition.

The high yielding genotypes, PCHL 04-34, ICCC 37 and ICCV 04110 were observed under non-irrigated condition, had also high values for MP (Table 4.2). It indicated that these genotypes may be obtained high yield potential under non-irrigated and irrigated conditions. Thus, the genotypes with the high yielding capacity and MP could be explained as tolerance to drought stress. Sadiq et al. (1994) reported that drought resistance may be present as an unidentified component of stability in genotype performance and provide an adequate assurance for farmers against environmental fluctuations in water-stress areas. A higher GMP value is indicating the tolerance to drought stress (Fernandez 1992). Based on these indices, ICCC 37, PCHL 04-34, ICCV 04110, PCHL 04-5 and ICCV 95311 were identified as drought tolerant genotypes (Table 4.2). Thus, both MP and GMP would be useful selection indices for identifying genotypes that perform well across a range of different environmental conditions.

A lower TOL and DSI values are indicating the tolerance to drought stress (Fernandez 1992; Deshmukh et al. 2004). Shwenilonegi, PCHL 04-34, PCHL 04-2, ICCV 03111 and ICCV 04306 were observed as drought tolerant genotypes due to their low quantity of TOL. It seems that TOL had succeeded in selecting genotypes with high yield under non-irrigated condition, but had failed to select genotypes with proper yield under both conditions.

Table 4.2. Drought tolerance indices of tested chickpea genotypes under non-irrigated and irrigated conditions at Zaloke Research Farm during post-monsoon season, 2009-2010

Genotypes	Drought Tolerance Indices					
	STI	DTE	MP	GMP	TOL	DSI
Annigeri	0.65	89.6	825.4	824.1	90.6	0.50
ICCC 37	1.36	86.5	1195.5	1192.3	173.3	0.65
ICCV 00108	1.00	52.4	1077.4	1023.6	672.5	2.30
ICCV 00401	0.72	71.8	879.4	867.5	288.4	1.36
ICCV 01303	0.53	80.4	750.9	746.5	162.9	0.95
ICCV 03103	1.15	86.6	1099.6	1096.8	157.9	0.65
ICCV 03107	0.45	88.0	691.1	689.7	88.2	0.58
ICCV 03110	0.78	74.4	910.8	900.9	267.5	1.24
ICCV 03111	1.01	96.3	1028.1	1027.9	38.9	0.18
ICCV 03203	0.69	86.8	848.8	846.7	119.5	0.64
ICCV 03302	0.70	69.4	869.3	855.0	313.7	1.48
ICCV 03403	0.57	85.2	774.8	772.3	124.0	0.72
ICCV 03406	0.72	76.7	877.9	870.2	231.6	1.13
ICCV 03407	0.51	59.9	754.3	730.1	378.8	1.94
ICCV 04103	0.60	69.2	807.5	794.0	293.9	1.49
ICCV 04110	1.34	83.9	1190.2	1185.7	207.7	0.78
ICCV 04111	0.91	80.0	982.3	976.2	218.1	0.97
ICCV 04301	0.68	89.9	841.4	840.2	89.9	0.49
ICCV 04303	0.59	55.5	822.8	788.4	471.1	2.15
ICCV 04304	0.79	84.6	910.4	907.3	151.7	0.74
ICCV 04306	0.89	95.6	967.4	967.2	43.7	0.21
ICCV 95311	1.28	79.5	1165.7	1158.1	265.8	0.99
ICCV 97024	0.44	86.4	680.3	678.5	99.4	0.66
ICCV 97306	0.85	85.6	943.2	940.4	145.8	0.69
ICCV 97314	0.44	84.5	680.3	677.9	114.3	0.75
Karachi	0.67	73.2	846.0	835.8	261.4	1.29
PCHL 04-2	1.17	99.0	1107.7	1107.7	11.2	0.05
PCHL 04-32	1.04	79.6	1048.3	1041.5	237.6	0.98
PCHL 04-34	1.35	101.0	1189.3	1189.3	-12.3	-0.05
PCHL 04-5	1.31	77.3	1178.7	1169.0	301.3	1.10
Shwenilonegi	0.64	104.9	820.8	820.5	-39.6	-0.24
Yezin 3	0.73	87.6	873.3	871.4	115.4	0.60
Yezin 4	0.57	63.2	795.0	774.5	358.6	1.78
Yezin 5	0.98	59.7	1044.0	1010.2	527.0	1.95
Yezin 6	0.87	76.2	963.8	955.0	260.0	1.15
ZCHL 05-2	0.41	67.6	664.9	652.4	256.9	1.56
ZCHL 05-20	0.84	92.9	938.4	937.8	68.7	0.34
ZCHL 05-73	0.61	63.0	817.4	796.1	370.6	1.79
ICC 4958 (C)	0.72	67.3	883.9	866.9	345.2	1.58

STI= Stress tolerance index, DTE (%) = Drought tolerance efficiency, MP= Mean productivity, GMP= Geometric mean productivity, TOL= Tolerance index, DSI= Drought susceptibility index

The DSI identified some genotypes, e.g. Shwenilonegi, PCHL 04-34, PCHL 04-2, ICCV 03111 and ICCV 04306 as drought resistant though they did not have outstanding yield performance in non-irrigated primarily because of their low potential yield (Appendix 3). The inherent problem with DSI for assessing drought tolerance is the emphasis placed on the change in genotypes performance from non-stress (irrigated) to stress (non-irrigated) conditions, rather than absolute performance. This can be well illustrated by comparing ICCC 37 and ICCV 03103. Both have similar DSI of 0.65 (Table 4.2), but ICCC 37 yielded significantly more than ICCV 03103 under non-irrigated and irrigated conditions (Appendix 3). This is because DSI is based on the minimization of seed yield reduction in non-irrigated compared to irrigated condition and therefore does not distinguish between genotypes showing tolerance and those showing poor response to favourable growing conditions. For this reason DSI should be used in combination with yield under non-irrigated (stress) condition to identify drought tolerant and productive genotypes under non-irrigated (stress) conditions. Thus, most appropriate selection index would depend upon objective of selection and target area.

Significant genotype x environment interaction for seed yield may also affect the consistency of drought tolerance indices. Many researchers (Bruckner and Frohberg 1987; Ehdaie et al. 1988; Clarke et al. 1992), who observed substantial differences in the DSI values in their experiments across different stress environments, also attributed the variation to genotypes x environment interaction.

According to the results of different indices of the present study, PCHL 04-34 was determined as the best drought tolerant genotype followed by ICCC 37, ICCV 04110, PCHL 04-2 and Shwenilonegi.

4.3.3 Correlation between seed yield under non-irrigated and irrigated conditions, and drought tolerance indices

Correlation between YNI (seed yield of the genotype under non-irrigated condition) and YI (seed yield of the genotype under irrigated condition) was significantly positive (r=0.61***), and it indicated that performance of genotypes under non-irrigated condition could be moderately determined by their performance measured under irrigated condition (Table 4.3). These results were in agreement with those of Toker and Cagirgan (1998) in chickpea and Yadav and Bhatnagar (2001) in

Table 4.3. Correlation between seed yield under non-irrigated and irrigated conditions and drought tolerance selection indices

Indices	YNI	YI	STI	DTE	MP	GMP	TOL	DSI
YNI	-							
YI	0.61***	-						
STI	0.92***	0.86***	-					
DTE	0.60***	- 0.25	0.26	-				
MP	0.90***	0.90***	0.99***	0.19	-			
GMP	0.92***	0.87***	1.00***	0.25	1.00***	-		
TOL	- 0.41**	0.47**	- 0.04	- 0.96***	0.04	-0.03	-	
DSI	- 0.60***	0.25	- 0.26	- 1.00***	- 0.19	-0.25	0.96***	-

, * Significant at the $p < 0.01$ and $p < 0.001$, respectively

YNI= Non-irrigated yield, YI= Irrigated yield, STI= Stress tolerance index, DTE= Drought tolerance efficiency, MP= Mean productivity, GMP= Geometric mean productivity, TOL= Tolerance index, DSI= Drought susceptibility index pearl millet, who reported that consistency in yield performance of genotypes was only low to moderate level under stress and non-stress conditions.

Correlation coefficients between drought tolerance indices and seed yield of genotypes under non-irrigated and irrigated conditions revealed that STI, MP and GMP had positive and significant relationship ($r=0.86$ to .0.92 at $p < 0.001$) with seed yield of genotypes under both conditions (Table 4.3). The similar result was reported by Toker and Cagirgan (1998) in chickpea. Therefore, these indices seem to be suitable for selection of genotypes that perform well across different environmental conditions. Moreover, selection based on the higher amounts of STI, MP, GMP and seed yield under non-irrigated and irrigated conditions provided the genotypes having high yield potential and tolerance to drought stress.

Drought susceptibility index (DSI) was negatively correlated with YNI ($r = -0.60^{***}$) but positively correlated with YI ($r = 0.25$). The similar results have been reported by Toker and Cagirgan (1998) in chickpea. Negative correlation between DSI and YNI was expected because genotypes that suffer less yield loss from irrigated to non-irrigated condition also tend to have high yield under non-irrigated condition. For this reason DSI should be used in combination with yield data under non-irrigated condition to identify drought tolerant and productive genotypes under non-irrigated condition. In this study, positive correlation between DSI and YI was observed but not significant. This indicated that chickpea genotypes selected for high yield under irrigated conditions could be more sensitive to drought stress. These results concur with those of Ceccarelli and Grando (1991) who suggested that some characteristics that contribute to yield potential may act to increase susceptibility to stress and that selection for both DSI and YI may counteract each other. However, Ehdaie et al. (1988) in wheat and Abebe et al. (1998) in dry beans found that there was no correlation between DSI and yield under optimum environments. These contrasting observations concerning the relationship between DSI and YI probably resulted from different species and also from differences in occurrence of drought, intensity and duration of stress.

Tolerance to drought stress (TOL) strongly correlated ($p < 0.01$) with DSI ($r = 0.96$) (Table 4.3). Therefore, it can be shown that these indices will produce similar results and to separate drought sensitive. In addition, based on the results of drought tolerance indices such as STI, DTE, MP and GMP indices have a similar ability to evaluate drought tolerant genotypes. Thus, they can be used to detect drought tolerant genotypes to grow in regions with limited water resources in order to extent cultivated area and increase production efficiency.

4.4 Conclusion

The yield data of tested genotypes showed a great variation in both non-irrigated and irrigated conditions. In general, the seed yield of genotypes under non-irrigated condition was remarkably lower than under irrigated condition. The seed yield under non-irrigated chickpea ranged from 536 to 1195 kg ha^{-1} and under irrigated conditions from 730 to 1414 kg ha^{-1}. The PCHL 04-34, ICCC 37, ICCV 04110, ICCV 95311 and PCHL 04-5 and PCHL 04-2, showed highest seed yield under non-irrigated condition (1028 - 1195 kg ha^{-1}) as well as irrigated condition (1183 - 1329 kg ha^{-1}).The results of the present study indicated that PCHL 04-34 was determined as the best drought tolerant genotype followed by ICCC 37 and ICCV 04110. Moreover, Shwenilonegi, PCHL 04-34 and PCHL 04-2 had highest drought tolerance efficiency (99%), and least drought susceptibility index (-0.24 to 0.05). More importantly, it maintained high values of HI above (0.50) under non-irrigated as well as irrigated condition.

Many researchers introduced mathematical models as yield-based selection indices for identifying high seed yielding genotypes under drought and optimum conditions. There is the need to incorporate drought tolerance mechanisms into germplasm with high yielding capacity to develop both high yielding and drought tolerant cultivars.

CHAPTER V

IDENTIFICATION OF TRAITS RELATED TO DROUGHT TOLERANCE IN CHICKPEA *(Cicer arietinum* L.)

5.1 Introduction

Chickpea (*Cicer arietinum* L.) is an important food legume crop because of its high quality protein for the human diet and its straw for valued animal feed. It is grown in over 50 countries in all continents of the world. The major chickpea growing countries fall in the arid and semi-arid regions where the crop is largely grown rainfed and terminal drought stress is a major cause for yield losses. A large portion of the losses can be prevented through crop improvement and better drought adapted genotypes would reduce the yield losses (Subbarao et al. 1995).

Several physiological, morphological and phonological traits have been listed to play a significant role in crop adaptation to drought stress (Ludlow and Muchow 1990; Saxena and Johansen 1990a; Subbarao et al. 1995). Alternative breeding strategies using physiological traits as selection criteria have been proposed by some researchers. Rapid progress in drought resistance breeding has been achieved in groundnut based on characters such as harvest index (HI), water use efficiency (WUE), specific leaf area (SLA), and SPAD chlorophyll meter reading (SCMR) (Nigam et al. 2005). Water use efficiency was associated with SCMR, SLA and carbon isotope discrimination ($\Delta^{13}C$) (Lal et al. 2006) and transpiration efficiency (TE) was also associated with SCMR, SLA and $\Delta^{13}C$ in chickpea (Kashiwagi et al. 2006c; Krishnamurthy et al. 2007). Early studies have indicated the differential responses for relative water content (RWC) in chickpea and it was positively correlated with chlorophyll content and grain yield in rice under drought conditions (Bahavar et al. 2009; Pirdashti et al. 2009).

In addition, information on the heritability of these traits will be useful for planning the suitable breeding strategies for improving drought tolerance. Phenotypic correlations among these traits are also important when simultaneous selection of multiple traits is to be carried out for high yield under drought stress conditions. Therefore, the objective of this study was to observe the seed yield under drought conditions and potentials yields, and to investigate the relationship of physiological traits related to drought tolerance.

5.2 Materials and Methods

5.2.1 Experimental site, design and plant materials

The experiment was carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (17° 30′ N; 78° 16′ E; altitude 549 m) during post-monsoon season, 2009-2010. The study of physiological traits and root traits were easily assessed. The soil of the experimental site was clay-loam Vertisol with slightly alkaline reaction (pH 8.31) (Appendix 4). Organic matter content of these soils was low (0.32%). This could be attributed to the prevailing dry conditions where the biomass production was low. Available phosphorus was very low for chickpea plant growth, moderate in available Zn, and rich in available potassium and exchangeable calcium.

This study was evaluated in two sets (non-irrigated and irrigated conditions) of 13 x 3 alpha designs with two replications. The tested 39 genotypes of chickpea were the same as in Sebin and Zaloke experiments.

5.2.2 Weather condition

Weather condition at the research location during crop growing period was shown in Appendix 5. Rainfall was 93 mm during the growing season. It can be suggested that drought stress in this study was not severe. However, this rainfall would not have significant effect on crop because it was not large amount and the soil was very low in organic matter content (Appendix 4).

5.2.3 Crop management

The field was prepared into 0.6 m ridges and furrows for both experiments. Incorporation of 18 kg N ha^{-1} and 20 kg P ha^{-1} (diammonium phosphate) was carried out in these experiments by surface application. The crop was grown on 10th November 2009 and harvested on 23rd February 2010. The plot size was 4 m x 0.6 m. Seeds were treated with 0.5 % Benlate + Thiram mixture to protect soil borne diseases. About 45 seeds were used for each 4 m row with a plant-to-plant spacing of 10 cm. Intensive protection against pod borer (*Helicoverpa armigera*) was provided by application of chemical sprays and the plots were kept weed free by manual weeding. Under irrigated treatment, furrow irrigation was applied at 40 days after sowing. Crop management for both trials was followed by ICRISAT's practices.

5.2.4 Data collection

Through regular observation, days to 50 % flowering, days to maturity were recorded. Canopy height, number of pods per plant, number of seeds per pod and 100-seed weight was recorded from 5 consecutive plants. Biomass yield and seed yield were recorded from 1 m row and harvest index (HI) was also calculated.

Drought tolerance traits such as SCMR, RWC and SLA were recorded at 45, 60, and 75 days after sowing (DAS) under non-irrigated condition, while the same traits were recorded at 45, 60, 75 and 90 DAS under irrigated condition.

5.2.5 Sampling for drought tolerance traits

5.2.5.1 SPAD chlorophyll meter reading (SCMR)

The SCMR reading was recorded with a Minolta handheld portable SCMR meter (SPAD-502 Minolta, Tokyo, Japan), at the third leaf from the top of the main stem of each plant and five leaflets were used for each sample collection.

5.2.5.2 Relative water content (RWC)

Relative Water Content (RWC) was measured at third leaf from the top of the main stem for each plant. The third leaf from the top of the main stem was detached from 5 randomly plants and kept in sealable plastic bag in an ice box. The leaf samples were brought to a laboratory where fresh weight was recorded immediately. The leaf samples were then immediately hydrated to be full turgidity for 2 hours by floating on de-ionized water in a close petri-dish under room temperature. After 2 hours the samples were taken out of water and were well dried with a filter paper. They were immediately weighted to obtain fully turgid weight (TW). Samples were then dried at 80 °C for 36 h and dry weight (DW) was determined. The RWC was calculated based on the formula mentioned by Gonzalez and Gonzalez-Vilar (2001) as follows:

$$\text{RWC (\%)} = \frac{\text{FW-DW}}{\text{TW-DW}} \times 100$$

where,

FW = fresh weight

TW = turgid weight

DW= dry weight

5.2.5.3 Specific leaf area (SLA)

The same samples were further measured for leaf area by using an image analysis system (WinRhizo, Regent Instruments INC., Quebec, Canada). The leaf samples were then oven-dried at 80°C until reaching constant weight and leaf dry weight was determined. The SLA was calculated as the following equation:

$$\text{SLA} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

5.2.6 Statistical analysis

The data from each individual experiment were analyzed using the following linear additive mixed effects model:

$$Y_{ijk} = \mu + r_i + b_{ij} + g_k + e_{ijk}$$

where,

Y_{ijk} = the observation recorded on genotype k in incomplete block j of replicate i

μ = the general mean

r_i = the effect of replicate i

b_{ij} = the effect of block j within replicate i

g_k = the effect of genotype k

e_{ijk} = the effect of the plot

The general mean μ and replicate effect r_i were considered as fixed effects. The block effect b_{ij}, the genotype effect g_k, and the plot effect e_{ijk}, were assumed as random effects each with mean zero and constant variances δ^2_b, δ^2_g and δ^2_e, respectively.

Using the above model, the statistical procedure of residual maximum likelihood (ReML) method with GenStat (version 12.1) statistical computing software was employed to obtain the unbiased estimates of the variance components δ^2_b, δ^2_g and δ^2_e, and the best liner unbiased predictions (BLUPs) of the performance of the genotypes.

Heritability was estimated as $h^2 = \delta^2_g / (\delta^2_g + \delta^2_e)$. The significance of genetic variability among genotypes was assessed from the standard error of the estimate of genetic variance δ^2_g, assuming the ratio δ^2_g/S.E. (δ^2_g) to follow normal distribution asymptotically.

The above model was extended for over-experiment analysis of traits recorded in both experiments, assuming environment (experiment) effect as fixed, with genotype x environment interaction (GEI) effect being a random effect assumed to have a mean of zero and constant variance δ^2_{gE}. The significance of GEI was determined in a manner similar to that of δ^2_g. The significance of the fixed effect of the environment was assessed using the Wald statiststic that asymptotically follows a χ^2 distribution and is akin to the *F*- test in the ANOVA.

5.3 Results and Discussion

5.3.1 Seed yield and morphological traits

In the combined analysis, the environment means (non-irrigated and irrigated) varied significantly for seed yield ($p < 0.01$), biomass yield ($p < 0.001$), harvest index ($p < 0.001$), days to maturity ($p < 0.001$) and number of pods per plant ($p < 0.01$) (Table 5.1). The genotypes were not significantly different for seed yield, biomass yield, harvest index, canopy height and pods per plant, but significantly differences were observed for days to maturity and seeds per pod among tested genotypes. However, there was a substantial variation in the genotype by environment (G x E) interaction for only biomass yield, and this effect may be attributed to the large variance component of the different environmental conditions (Table 5.1). The results indicated that the biomass yield of genotypes was largely environment-specific and the responses of genotypes were not the same across different environmental conditions.

The analysis showed significant genotypic differences ($p < 0.05$ to $p < 0.001$), for yield and yield related parameters under non-irrigated and irrigated conditions, except HI under non-irrigated condition (Table 5.2). The mean, range and heritability of seed yield were low under non-irrigated condition compared to irrigated condition. The result of present study was supported by Dhiman et al. (2006) who reported that moisture stress reduced chickpea yield due to poor partitioning operated along with terminal drought stress.

Under non-irrigated condition, the highest seed yield was found in PCHL 04-5 (2985 kg ha^{-1}) followed by ICCV 03107 (2905 kg ha^{-1}), Annigeri (2854 kg ha^{-1}), ICCV 00108 (2715 kg ha^{-1}) and the drought tolerant genotype ICC 4958 (2675 kg ha^{-1}), while the lowest in ICC 03406 (1351 kg ha^{-1}) (Appendix 6). This was due to significantly higher in their yield attributes *viz.*, biomass yield, HI and number of pods per plant of these genotypes. Under irrigated condition, the highest seed yield was observed in ZCHL 05-2 (3701 kg ha^{-1}) followed by Shwenilonegi (3605 kg ha^{-1}),

Table 5.1. Components of variance on seed yield and morphological traits of the chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

		Seed yield (kg ha^{-1})		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	13.25	1	13.25	0.005
Random term		Component		S.E.
Genotype (G)		28647		28725
G x E		65298		35745
Residual		147001		24866
		Biomass yield (kg ha^{-1})		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	31.55	1	31.55	<0.001
Random term		Component		S.E.
Genotype (G)		57776		122923
G x E		423368		165649
Residual		498244		83749
		Harvest index		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	45.42	1	45.42	<0.001
Random term		Component		S.E.
Genotype (G)		0.0005		0.0005
G x E		0.0011		0.0006
Residual		0.0030		0.0005
		Days to maturity		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	508.50	1	508.50	<0.001
Random term		Component		S.E.
Genotype (G)		8.48		2.40
G x E		0.91		0.94
Residual		5.30		0.89
		Canopy height (cm)		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	3.59	1	3.59	0.093
Random term		Component		S.E.
Genotype (G)		0.02		4.73
G x E		3.92		7.72
Residual		47.44		7.91

Table 5.1 (Contd.). Components of variance on seed yield and morphological traits of the chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

		Number of pods per plant		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	13.34	1	13.34	0.004
Random term		Component		S.E.
Genotype (G)		50.7		27.2
G x E		48.9		26.8
Residual		118.7		20.0
		Number of seeds per pod		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	1.51	1	1.51	0.252
Random term		Component		S.E.
Genotype (G)		0.00992		0.00280
G x E		0.00187		0.00103
Residual		0.00477		0.00079
		100-seed weight (g)		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Environment (E)	0.69	1	0.69	0.432
Random term		Component		S.E.
Genotype (G)		38.42		9.46
G x E		1.51		1.41
Residual		7.61		1.28

while the lowest yield was in Yezin 5 (1578 kg ha^{-1}).

The significantly differences ($p < 0.05$ and $p < 0.01$) were observed for biomass yield among the tested genotypes under both non-irrigated and irrigated conditions (Table 5.2). The mean and range of biomass yield were higher under irrigated condition compared to non-irrigated condition. It was also supported by higher heritability estimates for this character under irrigated condition. Under non-irrigated condition, the highest biomass yield was found in ICCV 03107 followed by ICC 4958 and PCHL 04-5. Omar and Singh (1997) reported that increased biomass yield in chickpea can contribute to higher seed yield. However, in the present study these high seed yielding genotypes could not produce the highest value of biomass yield under irrigated condition. These genotypes can be assumed as early maturing genotypes, which cannot accumulate large amount of total plant biomass due to reduced total photosynthetic period compared to the relatively longer maturing varieties.

The results of present study showed that the decrease in HI by irrigation. Pandey et al. (2001 and 2003) found that the decrease in HI by irrigation was due to suppression of flowering and number of pods. This led to a decreased requirement of dry matter and N in reproductive sink. Consequently, more of dry matter is retained in vegetative tissues. The results of present study showed that reduction in HI was of high magnitude in ZCHL 05-73 but it was not found in ICCV 00108, ICCV 04111, ICCV 04304, Yezin 3, ZCHL 05-20 and ICC 4958. Similarly, Dhiman et al. (2006) reported that HI was reduced under irrigated condition. The higher seed yielding genotypes also showed the value of HI more than 0.53 under non-irrigated condition. It is likely that the best-adapted genotypes will have a better balance between the vegetative and reproductive growth phases and achieve higher partitioning into seed (Saxena 2003). Improved HI represents increased physiological capacity to mobilize photosynthates from source to sink. Kumar et al. (2001) reported that HI as an important criterion for improvement in yield which is strongly influenced by environment.

Observations on days to maturity under two conditions revealed that there was a delay of 8-16 days in maturity in all genotypes under irrigated condition (Appendix 6). The reason may be the fact that the moisture stress creates internal stress on different parts, which quickens flowering and maturity. Similar observations were recorded by Dhiman et al. (2006) who reported that there was delay in maturity being

Table 5.2. Trial mean, range of best linear unbiased predicted means (BLUPs) and variance of seed yield and morphological traits of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

Traits	Trial mean	Range of predicted means	δ^2g	S.E	Significance	Heritability	
						h^2	S.E.
Seed yield (kg ha^{-1})							
Non-irrigated	2236	1351-2985	88991	38792	*	0.37	0.14
Irrigated	2725	1578-3701	101854	48153	*	0.42	0.13
Biomass yield (kg ha^{-1})							
Non-irrigated	4057	2633-5463	274905	128684	*	0.39	0.14
Irrigated	5654	3320-7773	667199	231757	**	0.53	0.12
Harvest index							
Non-irrigated	0.55	0.43-0.74	0.00086	0.00072	ns	0.18	0.16
Irrigated	0.49	0.35-0.65	0.0023	0.0008	**	0.51	0.12
Days to maturity							
Non-irrigated	90.0	82.5-96.3	8.77	2.86	**	0.58	0.11
Irrigated	101.6	94.1-107.6	10.07	2.83	***	0.70	0.08
Canopy height (cm)							
Non-irrigated	31.20	25.63-37.54	5.08	1.78	**	0.52	0.12
Irrigated	40.17	30.00-48.45	11.44	3.13	***	0.75	0.07
Pods per plant							
Non-irrigated	43.03	24.18-68.66	58.49	26.60	*	0.39	0.14
Irrigated	52.21	23.88-86.60	139.90	51.50	**	0.49	0.12
Seeds per pod							
Non-irrigated	1.08	0.99-1.35	0.01	0.00	**	0.66	0.09
Irrigated	1.10	0.99-1.39	0.01390	0.00373	***	0.75	0.07
100-seed weight (g)							
Non-irrigated	30.24	16.48-44.83	38.69	9.88	***	0.82	0.05
Irrigated	29.57	16.40-42.63	41.69	10.47	***	0.85	0.05

ns,*, **, *** Not significant, Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

20 and 10 days in desi and kabuli genotypes under irrigated condition. In the present study, PCHL 04-5 matured at 91days under non-irrigated and 107 days under irrigated condition, while Yezin 3, an early maturing genotype matured at 83 days and 94 days under non-irrigated and irrigated condition, respectively. Moreover, a large number of genotypes were observed as early maturity in (83-91 days) than ICC 4958 (96 days) under non-irrigated condition.

General reduction was observed in canopy height in all genotypes under non-irrigated condition, which indicated moisture stress occurred under non-irrigated condition (Table 5.2 and Appendix 6). Maximum reduction in canopy height was observed in ICCV 00401 from 48.5 cm under irrigated to 31.5 cm under non-irrigated condition. The values under irrigated condition ranged from 30.0 cm (Yezin 3) to 48.5 cm (ICCV 00401) and under non-irrigated condition ranged from 25.6 cm (Annigeri) to 37.5 cm (ICCV 04103). The high seed yielding genotype PCHL 04-5 attained a height of 31.1 cm and 39.8 cm under non-irrigated and irrigated condition, respectively. Heritability estimate for canopy height was higher under irrigated condition ($h^2 = 0.75$) than non-irrigated condition ($h^2 = 0.52$) (Table 5.2). It indicated that genetic variation for canopy height of these tested genotypes was high under non-water stress condition. Similar finding was reported by Dhiman et al. (2006). High estimates of heritability on plant heights were also reported by, Sharma et al. (1990), Misra (1991) and Rao et al. (1994).

The values of mean, range and heritability of number of pods per plant were lower under non-irrigated condition than under irrigated condition (Table 5.2). There were significant differences among the genotypes in number of pods per plant under both conditions. The highest value was given by genotypes ICCV 04110 (69) followed by PCHL 04-5 (66), while the lowest in ZCHL 05-2 (24) under non-irrigated condition. In the irrigated condition, the high seed yielding genotype PCHL 04-5 attained the same number of pods per plant as under non-irrigated condition, while the highest number of pods per plant was observed in ICCV 03107(87) and the lowest in ICCV 01303(24). Singh et al. (1997) reported that higher number of pods under stress has also been advocated as a criterion to identify stress tolerant plants. Therefore, PCHL 04-5 can be assumed as a drought stress tolerant genotype.

Concerning with seeds per pod and 100-seed weight, there were more or less constant values under both conditions. Similar result was reported by Dhiman et al. (2006) and these traits were less sensitive to environmental conditions, which were reflected in high estimates of heritability for these traits. The high seed yielding genotype PCHL 04-5 showed the highest number of seeds per pod (1.4) under non-irrigated and 1.3 under irrigated condition. Moreover, the 100-seed weight of PCHL 04-5 was 25.3 g under non-irrigated and 23.5 g under irrigated condition.

In this study, the genotypes under irrigated condition had much higher values in canopy height, pods per plant, and biomass yield than non-irrigated condition, indicating their higher efficiency in resource utilization. Moreover, high heritability estimates for these characters were provided under irrigated condition. The adverse effect of moisture stress on seed yield was clearly evident by its lowest value in the non-irrigated condition with 18 per cent reduction compared to irrigated condition. Leport et al. (1999) have also reported that 50-80 per cent reduction was found in chickpea genotypes exposed to terminal drought. The yield reduction can be described to statistically retarded performance of yield attributes especially pods per plant and biomass yield (Mathur et al. 2005). Similarly significantly lower values of these parameters were recorded under non-irrigated condition in the present study. However, the reduction in seed yield could not be observed in ICCV 03107, PCHL 04-5, Karachi, ZCHL 05-73, ICCV 01303, PCHL 04-34, ICCV 03407, ICC 4958, PCHL 04-2 and Yezin 5. It indicated that these genotypes may have inbuilt capacity to resist moisture stress effectively.

5.3.2 Correlation among seed yield and its components

In this study, most of the results reported on correlation between seed yield and yield components have shown that yield was positively associated with number of pods per plant and biomass yield under non-irrigated condition (Table 5.3). The present study thus suggested that selection for high seed yield should be emphasized on these characters. Kumar et al. (2003) also reported a positive correlation between pods per plant and seed yield. The positive correlation between seed yield and dry matter was reported by Turner (1997) and Siddique et al. (1999) who suggested that selecting genotypes or cultivars should be based on high dry matter production. The correlation coefficients between seed yield and pods per plant was small ($r = 0.01$) under irrigated condition and became larger ($r = 0.31$) under non-irrigated condition (Table 5.3). Similarly, the relationship between biomass yield and seed yield, also became stronger under non-irrigated condition ($r=0.86$) than under irrigated condition ($r=0.78$). The larger value of correlation coefficients of biomass yield with seed yield

Table 5.3. Correlation coefficients among yield components and seed yield of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

Traits	**Days to maturity**	**Canopy height**	**Pods per plant**	**Seeds per pod**	**100-seed weight**	**Biomass (kg ha^{-1})**	**Seed yield (kg ha^{-1})**	**Harvest index**
Days to maturity								
Non-irrigated	-							
Irrigated	-							
Canopy height (cm)								
Non-irrigated	0.17	-						
Irrigated	0.37*	-						
Pods per plant								
Non-irrigated	0.04	-0.14	-					
Irrigated	-0.13	-0.13	-					
Seeds per pod								
Non-irrigated	0.17	-0.20	0.20	-				
Irrigated	-0.17	-0.15	0.54***	-				
100-seed weight (g)								
Non-irrigated	0.11	0.45**	-0.53***	-0.51***	-			
Irrigated	0.13	0.40*	-0.66***	-0.55***	-			
Biomass yield (kg ha^{-1})								
Non-irrigated	0.31*	0.46**	0.20	0.11	0.03	-		
Irrigated	0.40*	0.47**	-0.06	-0.05	0.31*	-		
Seed yield (kg ha^{-1})								
Non-irrigated	0.21	0.21	0.31*	0.21	-0.19	0.86***	-	
Irrigated	0.04	0.33*	0.01	0.17	0.13	0.78***	-	
Harvest index								
Non-irrigated	-0.20	-0.40*	0.10	0.14	-0.32*	-0.27	0.22	-
Irrigated	-0.52***	-0.28	0.11	0.32*	-0.30	-0.44**	0.20	-

*, **, *** Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

under non-irrigated condition may have been due to increased genetic variance for biomass yield between moisture stress and non- stressed conditions (irrigated). These results indicated that pods per plant and biomass yield are effective yield attributes to increase seed yield at moisture stress condition, but less useful under irrigated condition. Singh et al. (1990) also noted that seed yield was directly and positively correlated with the biomass yield in chickpea.

According to the results of present study, number of pods per plant and biomass yield was positively and significantly associated ($r=0.31$ at $p < 0.05$ and $r=0.86$ at $p < 0.001$) with seed yield under non-irrigated condition. However, Talebi et al. (2007) suggested that selection for high seed yield should be based on biomass yield and HI. The positive relationship was also observed between seed yield and HI in the present study. It was an indication of better dry matter partitioning towards the reproductive parts. On the other hand, 100-seed weight was found to have a significant and negative correlation with pods per plant, seeds per pod and HI under non-irrigated and irrigated conditions. This finding was in agreement with Hassan et al. (2005) who reported that increase in seed yield through increase in number of pods per plant without effecting 100-seed weight may be used as a reliable selection criterion.

Based on the results of present study, nine genotypes (at least 2500 kg ha^{-1}) were selected. These genotypes were superior or similar to the seed yield of drought tolerant genotype ICC 4958 and also had good performance in both non-irrigated and irrigated conditions. The selected genotypes had large values in number of pods per plant (PCHL 04-5, Annigeri, ICCV 03107, ICCV 03110, ICCV 04103), biomass yield (ICCV 03107, ICCV 04103, ZCHL 05-2, ICCV 01303, PCHL 04-5), and HI (ICCV 03110, ICCV 03406, ICCV 00108 and ZCHL 05-2).

5.3.3 Physiological traits related to drought tolerance

Significant differences ($p < 0.05$ to $p < 0.001$) were observed for all physiological traits related to drought tolerance (SCMR, SLA and RWC) among the tested genotypes (Table 5.4). The times of observations also showed significant differences ($p < 0.001$) for all traits. Moreover, the time of observation by genotype (Time x Genotype) interaction were observed, except for RWC under non-irrigated condition.

Table 5.4. Analysis of variance for repeated measurements (45, 60, 75 DAS) of physiological traits of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Source of variation	df	MSS		F value		Probability	
		NI	I	NI	I	NI	I
SCMR							
Genotype	38	13.66	21.66	4.46	5.66	<0.001	<0.001
Time	2	746.03	669.84	243.48	174.98	<0.001	<0.001
Time x Genotype	76	5.82	6.74	1.90	1.76	<0.001	0.003
Residual	116	3.06	3.83				
SLA							
Genotype	38	2897.90	1822.00	5.48	2.83	<0.001	<0.001
Time	2	27867.40	8450.20	52.74	13.12	<0.001	<0.001
Time x Genotype	76	2313.80	1067.80	4.38	1.66	<0.001	0.007
Residual	116	528.40	644.20				
RWC							
Genotype	38	35.66	49.78	1.74	2.17	0.013	<0.001
Time	2	3738.16	2524.26	182.53	110.04	<0.001	<0.001
Time x Genotype	76	23.26	39.70	1.14	1.73	0.266	0.004
Residual	116	20.48	22.94				

5.3.3.1 SPAD chlorophyll meter reading (SCMR)

Combined analysis of variance showed significant differences ($p < 0.05$ and $p < 0.001$) among environments and tested genotypes for SCMR at all time of observations (Table 5.5). The interactions between genotypes and environment (G x E) were significant for SCMR at 60 DAS.

The SCMR value was highest at 60 and 90 DAS under non-irrigated and irrigated condition, respectively (Figure 5.1). Under non-irrigated condition, the value of SCMR showed a significant increase at 60 DAS and its significant decline again at 75 DAS. However, reverse linear growth of SCMR was observed under irrigated condition (Figure 5.1). Similar finding was reported in groundnut by Nigam and Aruna (2008). Significant differences in SCMR among tested genotypes were observed at 60 and 75 DAS under non-irrigated and at 45, 60 and 75 DAS under irrigated condition (Table 5.6). The highest heritability of SCMR (h^2= 0.57 under non-irrigated and 0.68 under irrigated condition) was observed at 60 DAS followed by 75 DAS (h^2= 0.56 under non-irrigated and 0.52 under irrigated condition).

Under non-irrigated condition, ICCV 03110 showed the highest SCMR of (63.58) and (70.07) at 45 and 75 DAS, respectively and ICCV 00108 showed the highest SCMR reading (71.36) at 60 DAS (Appendix 7). Under irrigated condition, these genotypes showed good performance in SCMR readings. From this study, the high yielding genotype PCHL 04-5 showed superior or similar SCMR to ICC 4958. The SCMR value of ICC 4958, drought tolerant genotypes showed higher from 45 DAS (59.52) to 75 DAS (68.15). Moreover, ICCV 2 which is widely grown in Myanmar had a good SCMR under non-irrigated condition at 60 DAS (67.69). At 90 DAS, the SCMR measurement was taken under irrigated treatment only because leaves of most of the genotypes under non-irrigated condition turned yellow color and senesced. Moreover, no significant difference was observed in SCMR among the tested genotypes.

In this study, the mean values of SCMR under non-irrigated condition were significantly higher than under irrigated condition and so drought factor seemed to increase the value of SCMR (Appendix 7). This finding agreed with Kashiwagi et al. (2006b) who reported that irrigation environment influence might be due to relatively less restricted leaf expansion and with relatively less chlorophyll formation under irrigated condition. In addition, the differences on crop growth rate and the nitrogen fixation ability between the irrigated and non-irrigated treatments possibly influence

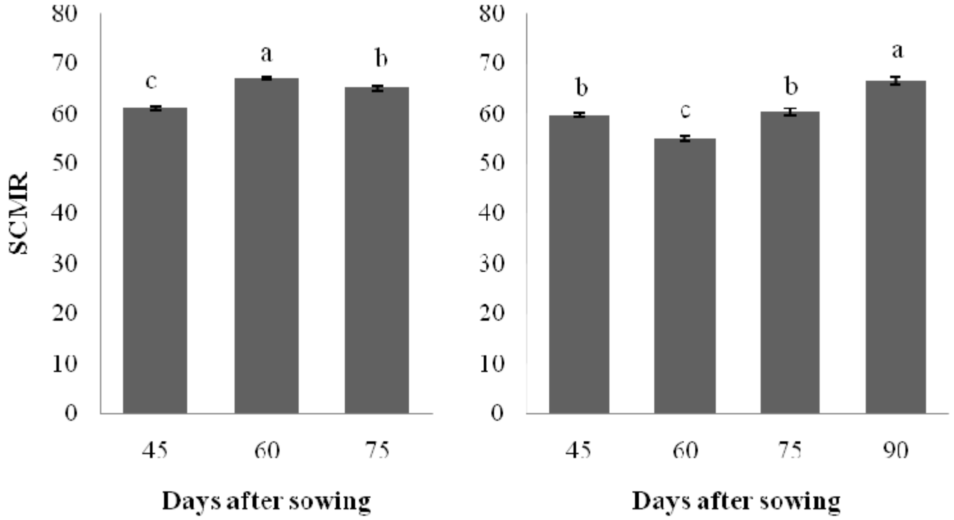
Table 5.5. Components of variance on SPAD chlorophyll meter readings (SCMR) of the chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

		SCMR at 45 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	7.7	1	7.7	0.028
Random term		Component		S.E.
Genotype (G)		1.777		0.547
G x E		-0.114		0.311
Residual		2.283		0.384
		SCMR at 60 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	1057.14	1	1057.14	<0.001
Random term		Component		S.E.
Genotype (G)		2.383		0.958
G x E		1.837		0.715
Residual		2.375		0.402
		SCMR at 75 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	31.97	1	31.97	<0.001
Random term		Component		S.E.
Genotype (G)		2.929		1.093
G x E		1.291		0.774
Residual		3.496		0.589

Table 5.6. Trial mean, range of best linear unbiased predicted means (BLUPs) and variance of SPAD chlorophyll meter reading (SCMR) of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

Traits	Trial mean	Range of predicted means	$\delta^2 g$	S.E	Significance	Heritability	
						h^2	S.E.
SCMR at 45 DAS							
Non-irrigated	60.93	57.37-63.58	0.93	0.58	ns	0.28	0.15
Irrigated	59.63	56.17-63.67	2.24	0.80	**	0.51	0.12
SCMR at 60 DAS							
Non-irrigated	67.00	63.12-71.36	2.52	0.81	**	0.57	0.11
Irrigated	54.93	49.33-61.74	5.93	1.73	**	0.68	0.09
SCMR at 75 DAS							
Non-irrigated	64.98	57.99-70.07	4.40	1.47	**	0.56	0.11
Irrigated	60.32	56.02-66.78	4.03	1.46	**	0.52	0.12
SCMR at 90 DAS							
Irrigated	66.54	61.35-72.73	1.88	2.45	ns	0.12	0.16

ns,*, **, Not significant, Significant at the $p < 0 .05$, $p < 0.01$



Non-irrigated condition **Irrigated condition**

Figure 5.1. Performance of SPAD chlorophyll meter reading (SCMR) of chickpea genotypes over time of observation at ICRISAT during post-monsoon season, 2009-2010

the chlorophyll concentration. Similar to the results of present study, drought significantly increased SCMR in groundnut (Upadhyaya 2005; Jongrungklang et al. 2008).

The present study has also shown that, ICCV 03110, ICCC 37 and ICCV 00108 showed superior and more consistent SCMR values than the others. Besides, ICC 4958 is a well known drought resistant genotype and had better SCMR. It was possibly due to its strong root systems (Kashiwagi et al. 2006b). On the other hand, Yezin 3 (ICCV 2) an extra-early in maturity had poor SCMR values as a consequence of the process of senescence and remobilization started in this and other early genotypes, leading to poor SCMR values (Kashiwagi et al. 2006b). In the present study, ICCV 2 matured at 94 days after sowing under irrigated condition and showed poor SCMR value. Leaf photosynthesis is generally correlated with chlorophyll content per unit leaf area and hence the SPAD chlorophyll meter reading can provide a useful tool to screen for genotypic variation in potential photosynthetic capacity under drought condition (Nageswara Rao et al. 2001; Songsri et al. 2009). The identification and use of surrogate traits for SCMR are simple and useful as a selection criterion for drought tolerance in peanut because of high heritability (Songsri et al. 2008).

5.3.3.2 Specific leaf area (SLA)

Combined analysis of variance showed significant differences ($p < 0.05$ to $p < 0.001$) for SLA among different environmental conditions at all observation times and tested genotypes at 60 and 75 DAS (Table 5.7). The interactions between genotypes and environment (G x E) were significant for SLA at all sampling times.

Low SLA is preferable as it indicates higher drought tolerance. There was a significant reduction in SLA under non-irrigated compared to irrigated condition at 45, 60 and 75 DAS (Table 5.7). Water deficit may have influenced leaf thickness by increasing number of chlorenchyma cells and chloroplasts per unit leaf surface area (Nobel 1991). Under non-irrigated condition, SLA showed significant declination at 60 DAS and it increased again at 75 DAS. Under irrigated condition, the SLA showed continually and significantly decline (Figure 5.2). In this study, genotypic differences for SLA were found to be significant at 45, 60 and 75 DAS under non-irrigated and 60 and 75 DAS under irrigated condition (Table 5.8). This finding was supported by good heritability of SLA at these sampling times.

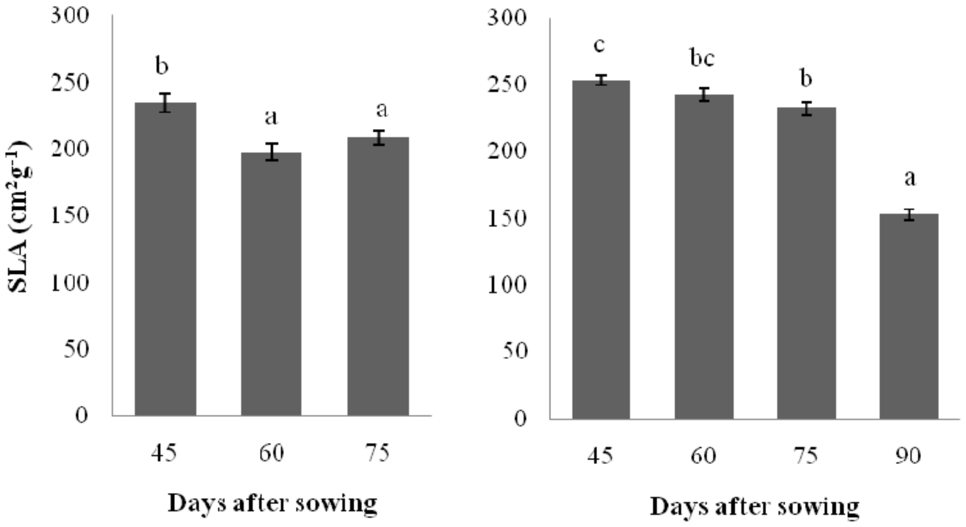
Table 5.7. Components of variance on specific leaf area (SLA) of the chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

		SLA at 45 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	7.11	1	7.11	0.022
Random term		Component		S.E.
Genotype (G)		120.9		138.7
G x E		357.9		175.9
Residual		705.6		118.8
		SLA at 60 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	60.65	1	60.65	<0.001
Random term		Component		S.E.
Genotype (G)		471.8		173.5
G x E		293.5		117.7
Residual		375.5		64.3
		SLA at 75 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	15.6	1	15.6	0.003
Random term		Component		S.E.
Genotype (G)		552.4		197.8
G x E		231.8		131.9
Residual		586.3		97.5

Table 5.8. Trial mean, range of best linear unbiased predicted means (BLUPs) and variance of specific leaf area (SLA) of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

Traits	Trial mean	Range of predicted means	δ^2g	S.E	Significance	Heritability	
						h^2	S.E.
SLA at 45 DAS							
Non-irrigated	234.4	178.6-339.1	973.8	301.7	**	0.63	0.10
Irrigated	253.0	221.7-308.7	-4.2	130.9	ns	-0.01	0.16
SLA at 60 DAS							
Non-irrigated	197.5	142.1-347.2	1126.6	297	***	0.79	0.06
Irrigated	242.5	193.1-298.3	409.6	157.3	*	0.50	0.12
SLA at 75 DAS							
Non-irrigated	208.8	150.8-291.5	913.3	290.2	**	0.59	0.11
Irrigated	232.2	185.3-306.3	650.2	225.9	**	0.53	0.12
SLA at 90 DAS							
Irrigated	152.7	102.7-209.7	-174.0	171.0	ns	-0.16	0.16

ns,*, **, *** Not significant, Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$



Non-irrigated condition **Irrigated condition**

Figure 5.2. Performance of specific leaf area (SLA) of chickpea genotypes over time of observation at ICRISAT during post-monsoon season, 2009-2010

At 45 DAS, ZCHL 05-2 gave the lowest SLA whereas the highest was given by PCHL 04-5 under non-irrigated condition (Appendix 8). This result was not consistent with irrigated condition. At 60 DAS, the lowest SLA was observed in ICCV 01303 (142.1 cm^2g^{-1}) followed by ICCV 03406 (157.5 cm^2g^{-1}) whereas the highest SLA was 347.2 cm^2g^{-1} of ZCHL 05-20 under non-irrigated condition. These genotypes also showed consistently lower SLA under irrigated condition. At 75 DAS, the lowest SLA was obtained in ICCV 04303 (150.8 cm^2g^{-1}) followed by ICCV 03302 (157.0 cm^2g^{-1}) and no consistent results were obtained under irrigated condition.

Although SLA was reduced by drought stress, SLA in certain genotypes under non-irrigated may be dependent on that under residual moisture conditions. The ICCV 01303, ICCV 04303, ICCV 04301 and ICCV 03302 showed consistently lower SLA than other genotypes at 60 and 75 DAS in both non-irrigated and irrigated conditions. In addition, the high seed yielding genotype PCHL 04-5 showed lower SLA than ICC 4958 at 60 and 75 DAS under the non-irrigated condition. The variation among the genotypes and their consistency of low SLA make it useful for the application as a selection criterion in drought tolerance breeding program

5.3.3.3 Relative water content (RWC)

Combined analysis of variance showed significant differences ($p < 0.001$) among different environmental conditions for RWC, except at 75 DAS (Table 5.9). There was no significant difference for RWC among the tested genotypes. The interactions between genotypes and environment (G x E) were significant for RWC at 60 and 75 DAS.

In the present study, RWC showed a significantly decreased at 60 DAS under non-irrigated and it significantly increased at 75 DAS. Moreover, RWC showed similar pattern of change over time of observations under irrigated condition (Figure 5.3). Significant differences ($p < 0.05$) among chickpea genotypes for RWC were found at 75 DAS under non-irrigated condition and at 60 and 75 DAS under irrigated condition (Table 5.10). The heritability of RWC was high (h^2= 0.35 under non-irrigated and 0.44 under irrigated condition) at only 75 DAS possibly due to the large genetic variation of RWC at this stage.

At 45 DAS, ICCV 03110 (85.35 %) and PCHL 04-34 (92.26%) showed high RWC in both non-irrigated and irrigated conditions (Appendix 9). At 60 DAS, ICCC 37 (78.31%) performed best for this character followed by Yezin 6 (73.91%) under

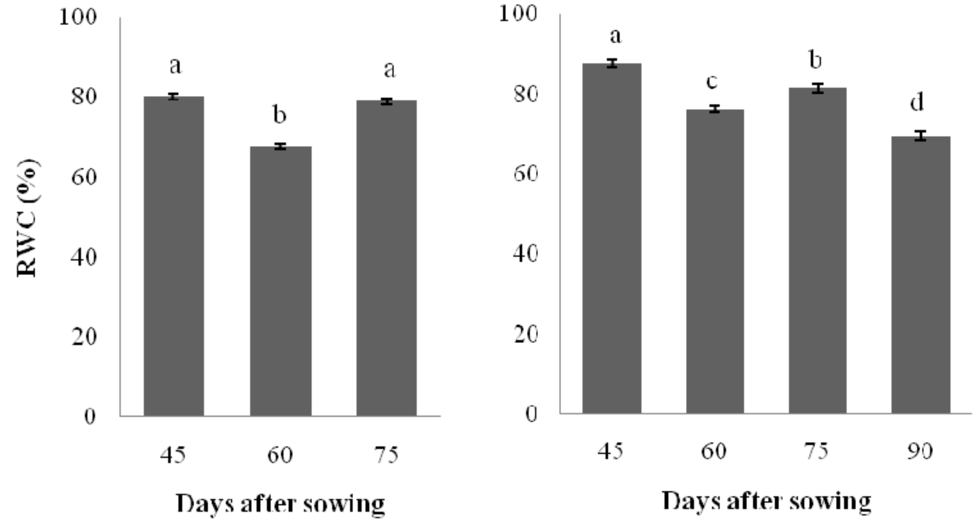
Table 5.9. Components of variance on relative water content (RWC) of the chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

		RWC at 45 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	54.76	1	54.76	<0.001
Random term		Component		S.E.
Genotype (G)		3.51		2.38
G x E		-0.28		3.02
Residual		21.05		3.54
		RWC at 60 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	69.82	1	69.82	<0.001
Random term		Component		S.E.
Genotype (G)		0.27		2.83
G x E		8.56		4.16
Residual		16.86		2.80
		RWC at 75 DAS		
Fixed term	Wald statistic	d.f	Wald/d.f	Chi-sq. probability
Experiment (E)	3.62	1	3.62	0.083
Random term		Component		S.E.
Genotype (G)		0.96		3.35
G x E		10.37		4.73
Residual		17.70		2.97

Table 5.10. Trial mean, range of best linear unbiased predicted means (BLUPs) and variance of relative water content (RWC) of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010

Traits	Trial mean	Range of predicted means	$\delta^2 g$	S.E	Significance	Heritability	
						h^2	S.E.
RWC at 45 DAS							
Non-irrigated	80.08	67.99-86.64	4.04	4.23	ns	0.15	0.16
Irrigated	87.57	79.54-94.16	2.48	3.84	ns	0.11	0.16
RWC at 60 DAS							
Non-irrigated	67.57	61.36-78.31	1.29	3.38	ns	0.06	0.16
Irrigated	76.21	65.01-86.40	14.35	6.03	*	0.48	0.13
RWC at 75 DAS							
Non-irrigated	78.97	69.66-86.03	13.35	6.54	*	0.35	0.14
Irrigated	81.44	70.90-95.85	9.18	3.78	*	0.44	0.13
RWC at 90 DAS							
Irrigated	69.51	57.41-86.29	3.08	7.81	ns	0.07	0.16

ns,*, Not significant, Significant at the $p < 0.05$



Non-irrigated condition **Irrigated condition**

Figure 5.3. Performance of relative water content (RWC) of chickpea genotypes over time of observation at ICRISAT during post-monsoon season, 2009-2010

non-irrigated condition. The results were in accordance with those for non-irrigated performance at 75 DAS. At 75 DAS, the highest RWC was observed in ICCV 00108 (86.03%) followed by Yezin 6 (85.84%). Kumar et al. (2003) reported that higher RWC indicates the genotypes with better osmoregulation.

The low value of RWC was recorded under non-irrigated condition, which might be due to the impact of lower soil moisture supply (Appendix 9). Similar findings have been reported by Swaraj et al. (1995) and Mathur et al. (2005). Relative water content in peanut is usually in a range of 30-100%, non-stressed plants have relative water content in a range of 85-100% (Reddy et al. 2003). According to Reddy et al. (2003), biochemical components in leaves of stressed plants were changed although the plants could maintain RWC as high as those for non-stressed plants and RWC in a range lower than 85% is considered severely stressed. In the present study, the mean value of non-irrigated condition for RWC was 67.57 % at 60 DAS and 78.97 % at 75 DAS. Thus drought occurred in this study between 60 and 75 DAS. Although there was no significant differences for RWC at 60 DAS, significant differences was observed at 75 DAS. However, consistent results of RWC were given by most genotypes at 60 and 75 DAS under non-irrigated condition. Similar findings were reported by Arunyanark et al. (2008) and Pimratch et al. (2008), who found that significant differences were observed for RWC between drought treatment and control treatment as early as 33-35 days after withholding water. According to this result, Yezin 6 and ICCC 37 had the highest RWC and may be assumed as promising genotypes for high RWC for drought tolerance.

5.3.4 Correlation among drought tolerance traits

Significant and negative correlations were found at 60 DAS between SLA and SCMR under non-irrigated and irrigated conditions (Table 5.11). Similar relationship between SLA and SCMR has been reported earlier in groundnut (Upadhyaya 2005). Genotypes with lower SLA (thicker leaves) are known to have more of photosynthetic mechanism, i.e. more chlorophyll content (Nageswara Rao and Wright 1994). In previous studies, the simple correlation between SLA and SCMR was reported under non stressed condition and end-of season drought condition (Wright et al. 1994; Nageswara Rao et al. 2001; Upadhyaya 2005; Nigam and Aruna 2008). In the present study, the materials were evaluated under both non-irrigated and irrigated conditions in the same trial. These findings showed that simple correlations between SLA and

Table 5.11. **Correlation coefficients among SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), relative water content (RWC), biomass yield and seed yield of chickpea genotypes under non-irrigated and irrigated conditions at ICRISAT during post-monsoon season, 2009-2010**

Traits	SCMR			SLA			RWC			Biomass (kg ha^{-1})	Seed yield (kg ha^{-1})
	45 DAS	60 DAS	75DAS	45 DAS	60 DAS	75DAS	45 DAS	60 DAS	75DAS		
SCMR at 45 DAS											
Non-irrigated	-										
Irrigated	-										
SCMR at 60 DAS											
Non-irrigated	0.45**	-									
Irrigated	0.45**	-									
SCMR at 75 DAS											
Non-irrigated	0.38*	0.21	-								
Irrigated	0.44**	0.44**	-								
SLA at 45 DAS											
Non-irrigated	0.09	0.24	0.11	-							
Irrigate	-0.20	-0.21	0.04	-							
SLA at 60 DAS											
Non-irrigated	-0.06	-0.32*	0.24	0.03	-						
Irrigated	0.16	-0.22	-0.01	0.01	-						
SLA at 75 DAS											
Non-irrigated	0.13	-0.20	-0.16	-0.35*	0.50***	-					
Irrigated	0.27	-0.16	-0.18	-0.06	0.55***	-					
RWC at 45 DAS											
Non-irrigated	-0.04	0.35*	0.05	0.20	-0.18	-0.26	-				
Irrigated	0.08	0.17	0.01	-0.02	0.32*	0.23	-				
RWC at 60 DAS											
Non-irrigated	0.13	0.21	0.28	-0.02	0.32*	0.22	0.20	-			
Irrigated	0.10	0.18	-0.10	0.03	-0.20	0.00	0.15	-			
RWC at 75 DAS											
Non-irrigated	0.24	0.12	0.02	0.05	0.01	-0.08	-0.03	0.30	-		
Irrigated	0.12	0.09	0.00	-0.02	0.06	-0.05	0.02	0.01	-		
Biomass yield (kg ha^{-1})											
Non-irrigated	-0.03	-0.14	0.35*	0.02	0.14	0.22	0.20	0.01	-0.19	-	
Irrigated	0.20	-0.42**	0.01	0.08	0.15	0.34*	-0.24	0.10	0.08	-	
Seed yield(kg ha^{-1})											
Non-irrigated	0.00	-0.08	0.32*	0.05	0.10	0.29	0.15	0.01	-0.07	0.86***	-
Irrigated	0.25	-0.21	0.17	0.08	0.09	0.25	-0.07	0.09	0.05	0.78***	-

*, **, *** Significant at the $p < 0.05$, $p < 0.01$, $p < 0.001$

SCMR were observed under non-irrigated condition and also at later stage of the crop growth. Moreover, significant and positive correlations were also found at 60 DAS between SLA and RWC under non-irrigated condition. Under non-irrigated condition, SCMR showed a significant increase whereas SLA and RWC showed a significant decrease at 60 DAS (Figures 5.1; 5.2; 5.3). However, SLA and RWC showed an increase at 75 DAS but the difference was not significant in SLA and significant in RWC. On the other hand, SCMR showed significantly declined at 75 DAS.

Although there was a significant linear correlation for SCMR and SLA between at 60 and 75 DAS within the irrigated treatment ($r = 0.44$ at $p< 0.01$) and ($r = 0.55$ at $p < 0.001$), there also existed a significant G × E interaction ($p<0.001$) reflecting the effects of duration on SCMR and SLA observations. This suggested that 75 DAS of crop growth could be used at applicable time of observations. Kashiwagi et al. (2006b) suggested that SCMR recording was proposed at early stages of the crop (62 DAS). Nigam and Aruna (2008) suggested that SCMR and SLA can be recorded in groundnut at any time after 60 days of the crop growth, preferably under moisture deficit conditions. However, as suggested by Serraj et al. (2004b), these measurements should be recorded after imposition of moisture deficit and particularly at mid-way through stress.

Chickpea genotypes showed different responses for traits associated with drought tolerance and the genotypes with good performance for traits associated with drought tolerance could be identified. According to this result, the linear growth phase of the genotypes for SCMR, SLA and RWC was different leading to a crop growth stage x genotype interaction. Such interactions would create difficulties in identifying the best genotype for drought tolerance traits. However, ten genotypes have been selected which were superior or similar to check genotype for SCMR, SLA and RWC. ICCV 03110, ICCC 37 and ICCV 00108 were good genotypes for SCMR while ICCV 01303, ICCV 04303, ICCV 04301 and ICCV 03302 were good genotypes for SLA and Yezin 6, ICCC 37 and ICCV 00108 had high RWC at all time of observations. Differential responses of genotypes for these traits indicated that several drought resistance mechanisms might exist. In addition, most of the drought tolerance traits in this study had good heritability estimates, indicating that breeding progress could be achieved for these characters. Integrating these characters in chickpea breeding programs could increase drought tolerance in chickpea.

5.3.5 Correlation between drought tolerance traits and seed yield

Correlations between drought tolerance traits and seed yield provided information on expected responses in yield from selection for drought tolerance traits. At 75 DAS under non-irrigated condition, a significant positive relationship was observed between SCMR and seed yield ($r = 32$ at $p < 0.05$) and biomass yield ($r = 35$ at $p < 0.05$) (Table 5.11). The SCMR is known to be related to leaf N content in several crops (Schepers et al. 1992; Uzik and Zofajova 2000; Veeraputhiran et al. 2001). Higher SCMR seems to be an indication of the genotype's capacity for higher carbon assimilation and in turn seed yields even under moisture-limited situation.

In this study, drought tolerance traits (RWC, SCMR, and SLA) were not correlated with biomass yield and seed yield under non-irrigated condition, except for SCMR (Table 5.11). More greenish plants yielded more biomass yield and seed yield than plants with lighter colour under stress condition. The SCMR is an indicator of the photo-synthetically active light-transmittance characteristics of the leaf, which is dependent on the unit amount of chlorophyll per unit leaf area (Chlorophyll density) (Richardson et al. 2002). Significant and positive correlation between SCMR and chlorophyll content was observed and SCMR was also closely related with chlorophyll density (Arunyanark et al. 2009).

Based on the present results, the significant interrelationships between SLA and SCMR suggested that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA. Nageswara et al. (2001) reported that SCMR could be used as a reliable and rapid measure to identify genotypes with low SLA or high SCMR which are surrogate measures of Transpiration Efficiency (TE) in groundnut. Gupta et al. (1989) reported that a significant positive correlation exists between the photosynthetic rate and the specific leaf weight (SLW, reverse of SLA) at the pod filling stage. The present observation also supported the earlier report of positive correlation between seed yield and SLA by Katiyar and Katiyar (1994). In cowpea studied under mid-season drought, the high RWC of leaves was maintained in some of the genotypes by stomata closure and a reduction of leaf area. Drought avoidance by maintaining high leaf water content was negatively associated with SLA (Anyia and Herzog 2004).

The SCMR and SLA are surrogate traits of WUE and had low correlation with seed yield (Nageswara Rao and Wright 1994; Wright et al. 1994; Sheshshayee et al. 2006). In this study, however, SCMR had higher correlations with seed yield and biomass yield under non-irrigated condition than did SLA. Among drought tolerance traits (SCMR, SLA and RWC) SCMR had the highest correlation with seed yield and the measurement of SCMR was easy and simple. Moreover, these traits have lower G × E interaction than SLA and RWC. It would be possible to improve yield by selecting high SCMR. The SCMR is an indicator of the photosynthetically active light-transmittance characteristics of the leaf and positive correlated with chlorophyll content (Akkasaeng et al. 2003) and chlorophyll density (Arunyanark et al. 2008) and WUE (Sheshshayee et al. 2006). Nonetheless, the integration of physiological traits (or their surrogates) in the selection scheme would be advantageous in selecting genotypes that are more efficient water utilizers [SCMR (surrogates trait)] or partitioners of photosynthates into economic yield (HI) (Nigam et al. 2005). The SPAD chlorophyll meter provided an easy opportunity to integrate a surrogate measure of WUE with seed yield, in the selection scheme of a drought tolerance breeding program in chickpea.

5.4 Conclusion

Lower seed yield, larger SCMR, lower SLA and RWC indicated that non-irrigated condition suffered from more moisture stress to certain extent than irrigated condition. A comparison of drought tolerance traits under non-irrigated versus irrigated condition could provide a better understanding of the most suitable conditions for selecting drought tolerant genotypes. Significant correlations between traits under non-irrigated and irrigated conditions were found in the tested genotypes for SCMR, seed yield, and biomass yield, indicating that these traits could be used either under non-irrigated or irrigated condition. Heritability estimates were good in both non-irrigated and irrigated conditions and the traits under different environments were correlated well. This provides chickpea breeders a large flexibility to apply these observations in a large number of segregating populations and breeding lines in the field, thus making it easy to incorporate these physiological traits associated with drought tolerance in breeding and selection schemes in chickpea. The relative usefulness of secondary traits (SCMR and SLA) as indicated selection criteria for a primary trait (seed yield) was determined by the magnitudes of the genetic variance, heritability and correlation with the primary traits (seed yield). This study identified the utility of SCMR as an indirect selection criterion for seed yield under drought condition.

CHAPTER VI

GENETIC VARIABILITY OF DROUGHT-AVOIDANCE ROOT TRAITS IN CHICKPEA (*Cicer arietinum* L.) GENOTYPES

6.1 Introduction

Chickpea is mostly grown during the post-monsoon season in deep clay soil and depends on the residual moisture contained in the soil profile, therefore facing water deficit in the later part of the growth cycle. The major chickpea growing countries fall in the arid and semi-arid zones where the terminal drought stress is a major cause for yield losses. As water resources become limiting for crop production in dry areas, the management of drought becomes increasingly important. Although irrigation has lead to more assured grain yields with the use of improved disease tolerant genotypes, a major proportion of the world's future chickpea production is likely to continue to come from rainfed agriculture (Saxena 1984; Silim and Saxena 1993).

Drought or water deficiency can be managed at the plant level through drought escape and drought resistance mechanisms (Levitt 1980). Drought resistance can further be described in terms of dehydration avoidance and dehydration tolerance mechanisms. Roots have a major role in dehydration avoidance as a deep root system is able to obtain more moisture from the deeper soil layers even when the upper soil layer becomes dry.

Studies in various crops have shown the importance of a deep root system for extracting moisture under terminal drought stress (Ludlow and Muchow 1990; Saxena and Johansen 1990b; Turner et al. 2001). Kashiwagi et al. (2006a) found substantial variation in root length density among 12 diverse kabuli and desi chickpea genotypes grown under terminal drought stress. The proportion of the roots at the lower depth is also important in water absorption from deeper soil layers. Roots at the deeper soil layer contribute more to root length or surface area than to root weight (Follett et al. 1974). Deep root systems in sorghum demonstrate increased yield under drought conditions (Sinclair 1994). A high ratio of deep root weight to shoot weight also maintains higher plant water potential and has a positive effect on yield under stress conditions (Mambani and Lal 1983). Therefore, roots are only one component of the overall performance of crop under terminal drought conditions, and it needs to be addressed together with other traits.

Conducting research on root systems in a field condition is very laborious, expensive and time-consuming (Subbarao et al. 1995). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has established a modified monolith method (Serraj et al. 2004c) which is fairly reliable and allows systematic field root extraction at a root sampling. Although this method is fairly reliable, it cannot be employed for large scale screening of genotypes. The pot culture method is less cumbersome but rooting profile cannot be estimated in shallow pot grown plants. Thus, extensive efforts have been made at ICRISAT to optimize a polyvinyl chloride (PVC) cylinder culture system as an alternative method that allows screening of a large number of genotypes. There was also close association of genotypic performance under 70 % field capacity (FC) cylinder with that of the field suggests that the cylinder protocol could be adapted for screening studied of root traits (Kashiwagi et al. 2006a). The objectives of this study were to assess the extent of genetic variation available for the root traits of chickpea genotypes and relationships among these traits.

6.2 Materials and Methods

6.2.1 Experimental site, design and plant materials

This study was carried out at rain-out shelter of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India (17° 30´ N; 78° 16´ E; altitude 549 m). The experiment was laid out in a randomized complete block design with two replications. Forty chickpea genotypes were used which comprising ICC 4958, the drought genotype, and ICC 283, the poor genotype in root system which were recommended by ICRISAT.

6.2.2 Preparing the cylinder culture

Cylinders (1.20 m length x 0.16 m diameter) were created using polyvinyl chloride (PVC) drain pipes to provide enough space for root growth. The cylinders were placed in 1.2 m cement pits to mimic field growth conditions and gaps among cylinders were filled with paddy straw to protect incidence of direct solar radiation. The cylinders, except the top 15 cm, were filled with an equal-mixture (w/w) of Vertisol and sand, mixed with di-ammonium phosphate at the rate of 0.07 g kg^{-1}. A mixture of soil and sand was used to decrease the soil bulk density and facilitate root growth and extraction**.** The soil water content of the mixture was equilibrated to 70%

FC to create the conditions similar to those in the field at sowing time, where the soil was not fully saturated with water. To prepare 70% FC soil, 113 g of water was required for a kilogram of dry soil.

The top 15 cm of the cylinder was filled with the same soil-sand mixture in the dry condition. Four seeds of each genotype were sown in the cylinder and then irrigated with 500 ml of water immediately after sowing and twice on alternate days with 150 ml until the seedlings uniformly emerged. After that, no irrigation was given so as to create the terminal drought conditions and later the plants were allowed to grow on progressively receding soil moisture. The plants were thinned to be two plants per cylinder at 7 DAS. The plants were protected from rainfall by using a movable rain-out shelter.

6.2.3 Data collection

The rooting depth (RDp), root dry weight (RDW), root length density (RLD), total root length (TRL), root surface area (RSA), root volume (Rvol), and shoot dry weight (SDW) were measured at harvest (35 DAS). The RDp was measured from the cotyledonary point to the deepest root tip. The RLD is an indicator of the capability for soil water exploitation, while the root to total plant dry weight ratio (R/TDM) that indicates the relative root biomass distribution was calculated. The RLD and R/TDM was calculated as follows;

$$\text{RLD} = \frac{\text{Total root length per cylinder (cm)}}{\text{Cylinder volume at the maximum rooting depth (cm}^3\text{)}}$$

$$\text{R/TDM} = \frac{\text{Total root dry weight (g)}}{\text{Total root and shoot dry weight (g)}}$$

(Kashiwagi et al. 2006a)

6.2.3.1 Root and shoot sampling

The roots were sampled at 35 DAS avoiding physically damaged plants. The previous studies showed that maximum variation in root dry weight and root length density among genotypes were well noticed in this environment at this stage, and that variation is reduced after 41 DAS (Krishnamurthy et al. 1996). After harvesting the shoots, the cylinders were placed horizontally and the sand-soil mixture was removed gently with the help of running water. When approximately three-quarters of the filled soil-sand mixture were washed away, the cylinder was erected gently on a 3 mm sieve so that the entire root system could be easily collected. The roots were thoroughly cleaned by repeated dipping and rising in buckets of clean water. After removing the soil particles, the whole roots were straightened to estimate the maximum rooting depth. Then, the whole root was divided into layers of 30 cm and scanned using WinRhizo Pro2004a (Regent instruments, Inc., Quebec, Canada) at 400 dpi (Gaur et al. 2008). The captured grayscale image was analyzed with WinRhizo to measure root length, root surface area and root volume at each of the 30 cm depth of the root system, and following a methodologies previously described by Serraj et al. (2004c). After completion of measurements with the digital image analysis system, root samples were dried at 80°C for 72 hours. The shoot and root dry weights were recorded after drying in a hot air oven.

6.2.4 Statistical analysis

The data were subjected to analysis of variance and the simple correlation coefficients between root traits were also calculated. All calculations were accomplished by using GenStat (version 12.1) software program. Broad sense heritability was estimated as mentioned by Singh et al. (1993).

$$h^2 = \frac{\delta^2{}_g}{\delta^2{}_g + \delta^2{}_e}$$

Where,

$\delta^2{}_e = M_e$

$\delta^2{}_g = (M_g - M_e)/b$

$\delta^2{}_e$ = Environmental variance

M_e= Mean square of error

$\delta^2{}_g$= Genotypic variance

M_g= Mean square of genotype

b= Replication

6.3 Results and Discussion

6.3.1 Rooting depth (RDp)

There was a significant genotypic variability ($p < 0.05$) of rooting depth with heritability (h^2) of 0.34 (Table 6.1). Kashiwagi et al. (2005) reported that the largest genetic variability was observed at 35 DAS with broad sense heritability estimates of 0.36 for RDp. Maximum RDp was observed in PCHL 04-34 (113 cm) closely followed by ICCV 03203 (110.5 cm) and Swenilonegi (108.0 cm) (Figure 6.1 and Appendix 10). The rooting depth of PCHL 04-34 and ICCV 03203 were significantly deeper than that of ICC 4958, the drought tolerant check genotype. In chickpea, the rooting depth is an important characteristic to improve drought tolerance (Kashiwagi et al. 2006a).

Chickpea is one of the deepest rooting species among the cool season food legumes. In the present study, the RDp was observed from 68.5 cm to 113 cm. Krishnamurthy et al. (1996) reported that genotypic variation according to RDp is available and is normally about 1.20 - 1.35 m with large environmental variations. A deep root system seems to be related to yield under drought stress. The root system in chickpea is likely to be sub-optimal at depths below 75 cm because large amount of water were left unextracted at maturity. The advantage of a deep root system towards drought tolerance was also substantial in soybean (Kaspar et al. 1978), common bean (Sponchiado et al. 1989) and chickpea (Silim and Saxena 1993).

6.3.2 Root dry weight (RDW)

Root dry weight showed large genotypic variability ($p < 0.01$) as well as relatively high heritability ($h^2= 0.39$) (Table 6.1). For other legumes, however, broad sense heritability estimates of 0.51- 0.61 for root mass in common bean under limited soil phosphorus supply have been reported (Araujo et al. 2005). In the present study, PCHL 04-34, PCHL 04-32, Shwenilonegi, ICC 4958, Yezin 6 and ICCV 03103 had the highest root dry weight in a descending order, which were different from that of ICC 283 check (Figure 6.2). Root biomass as well as rooting depth was recognized as the main drought avoidance trait to improve seed yield (Ludlow and Muchow 1990; Subbarao et al. 1995; Turner et al. 2001).

6.3.3 Root length density (RLD)

Root length density also exhibited a large variation ($p< 0.01$) with a good level

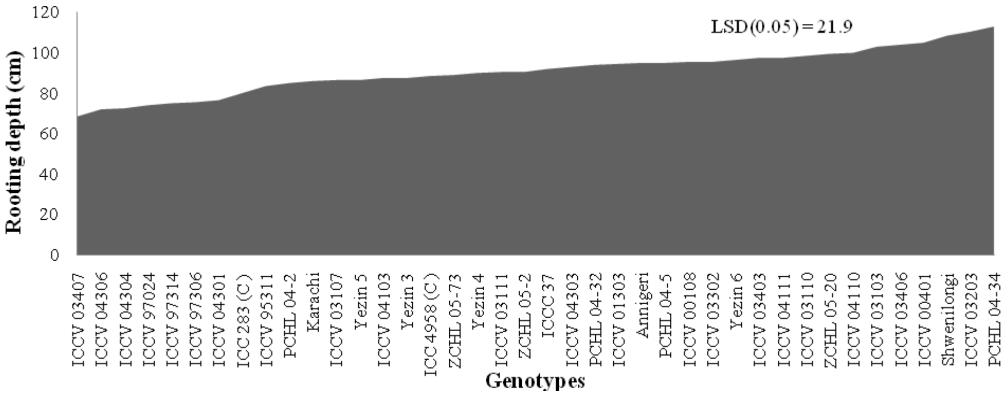


Figure 6.1. Rooting depth of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010

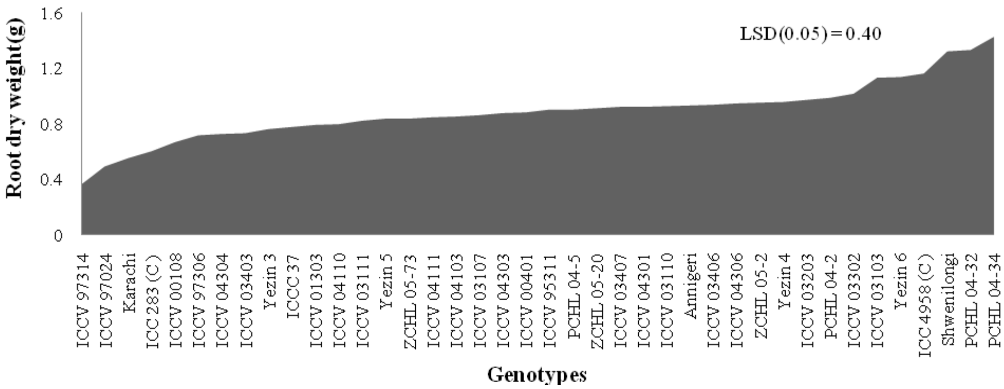


Figure 6.2. Root dry weight of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010

of heritability (h^2= 0.44) (Table 6.1). Kashiwagi et al. (2005) reported that the largest genetic variability was observed with broad sense heritability estimates of 0.51 and 0.54 across seasons for RLD. The results of present study showed that maximum RLD was found in ICCV 04301 followed by PCHL 04-32, Yezin 6, Shwenilonegi and Annigeri with the range of 0.45 to 0.40 cm cm^{-3},which were not different from ICC 4958 (0.38 cm cm^{-3}) (Figure 6.3 and Appendix 10). However, the mean RLD of these genotypes were significantly different from that of the poor genotype, ICC 283. The root traits such as depth, length density, and biomass have been proposed as the main drought avoidance traits to contribute to seed yield under terminal drought environments (Ludlow and Muchow 1990; Subbarao et al. 1995; Turner et al. 2001; Kashiwagi et al. 2005).

6.3.4 Root dry weight to whole plant dry weight ratio (R/ TDM)

The ratio of root to the whole plant dry weight also showed significant differences ($p < 0.05$) with the heritability value of 0.29 (Table 6.1). However, the patterns of distribution among the chickpea genotypes differ from that of other traits (Figure 6.4). The highest ratio was attained in ICCV 95311 followed by Yezin 5 and ICCV 04110, which were not significantly different from that of ICC 283 and ICC 4958.

In the present study, average of about 36% of the total plant dry matter was allocated to the roots at the sampling time (35 DAS) (Appendix 10). Kashiwagi et al. (2005) reported that 40 % of the total dry matter was accumulated as root in chickpea and a similar ratio (36%) was observed in cowpea (Ismail and Hall 1992). This ratio is relatively high compared to rainfed lowland rice that has less than 20% in average (Azhiri-Sigari et al. 2000). This would indicate that both chickpea and cowpea have developed relatively prolific root systems compared to other annual species to be able to acquire more available soil water.

6.3.5 Total root length (TRL)

The chickpea genotypes varied significantly ($p < 0.01$) for total root length with heritability (h^2) of 0.38 (Table 6.1). In common bean, broad sense heritability estimates of 0.47 - 0.50 for root length has been reported under limited soil phosphorus supply (Araujo et al. 2005). In the present study, total root length was maximized in PCHL 04-34, Shwenilonegi, Yezin 6, PCHL 04-32, ICCV 03103 and

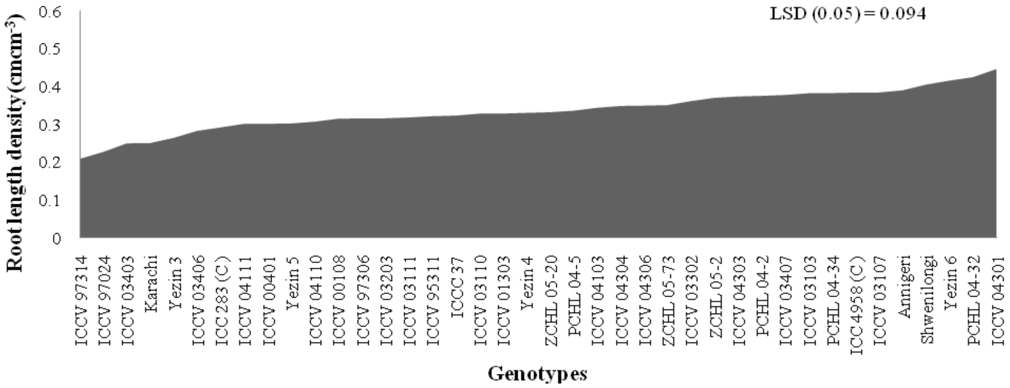


Figure 6.3. **Root length density of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010**

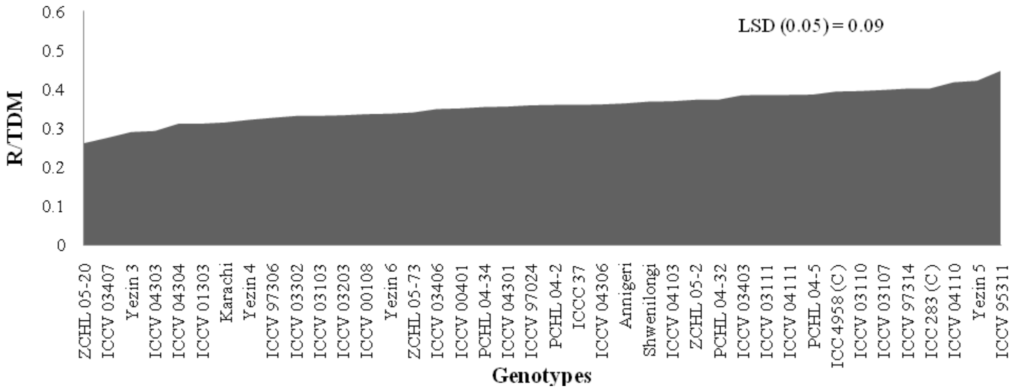


Figure 6.4. **The ratio of root to total plant dry weight of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010**

Annigeri (Figure 6.5). The lowest TRL was occurred in ICCV 97314.

6.3.6 Root surface area (RSA)

Root surface area did not show any different among chickpea genotypes with heritability of 0.25 (Table 6.1). However, broad sense heritability estimates of 0.51-0.55 for root area have been reported in common bean (Araujo et al. 2005). The maximum root surface area was found in PCHL 04-34, ICCV 03103, PCHL 04-32, Yezin 6 and Shwenilonegi as in TRL (Figure 6.6).

6.3.7 Root volume (RVol)

There was no significant genotypic variability in root volume with a low level of heritability (h^2= 0.15) (Table 6.1). The maximum value of root volume was found in the same trend as in root surface area and total root length (Figure 6.7).

6.3.8 Shoot dry weight (SDW)

For plant growth indicated by SDW, also exhibited a large variation among the genotypes and with a good level of heritability (h^2= 0.46) at 35 DAS (Table 6.1). Moreover, PCHL 04-34. ICCV 03407, ZCHL 05-20, Shwenilonegi, PCHL 04-32, and Yezin 6 attained vigorous plant growth (Figure 6.8). Early shoot growth vigor is another improtant trait which contributes to terminal drought tolerance in chickpea (Saxena and Johansen 1990b; Turner et al. 2001).

6.3.9 Distribution of root length density

The RLD was higher in the upper soil layer (0-60 cm depth) than in deeper layers (60-120 cm) (Appendix 11). At the upper soil layer, the highest range of genetic variation was found. The genotypes Shwenilonegi, ICCV 04301, Yezin 6, PCHL 04-34 and ICC 4958 had the most the prolific root system (Figure 6.9). However, the difference in mean RLD was also minimal in the deeper soil layer (Figure 6.10). This would indicate occurrence of more branching in the upper soil layer and very less branching of roots in the deeper soil layer. These findings are agreement with Kashiwagi et al. (2005) and reported that more branching of root occurred at 0-30 cm soil layer and less branching of roots after 30-60 cm soil layer. Moreover, the difference in mean RLD was also found between 0-30 and 60-90 cm (Figure 6.11). The mean RLD, however, did not vary between 30-60 and 90-120 cm

Table 6.1. Analysis of variance on root and shoot traits of the chickpea genotypes at ICRISAT during post-monsoon season, 2009-2010

Trait	Mean	Minimum	Maximum	Significance	CV%	Heritability (h^2)
RDp	90.8	68.5	113.0	*	11.9	0.34
RDW	0.89	0.37	1.43	**	22.1	0.39
RLD	0.34	0.21	0.45	**	13.8	0.44
R/ TDM	0.36	0.26	0.45	*	12.0	0.29
TRL	6171	3145	8701	**	19.0	0.38
RSA	1387	727	2012	ns	23.0	0.25
RVol	25.38	12.83	38.44	ns	28.0	0.15
SDW	1.67	0.54	2.60	**	23.6	0.46

ns, *, **, Not Significant, Significant at the $p < 0.05$, $p < 0.01$

RDp= Rooting depth (cm), RDW = Root dry weight (g), RLD = Root length density (cm cm^{-3}), R/TDM= Root dry weight/ whole plant dry weight, TRL = Total root length (cm), RSA=Root surface area (cm^2), RVol= Root volume (cm^3), SDW = Shoot dry weight (g)

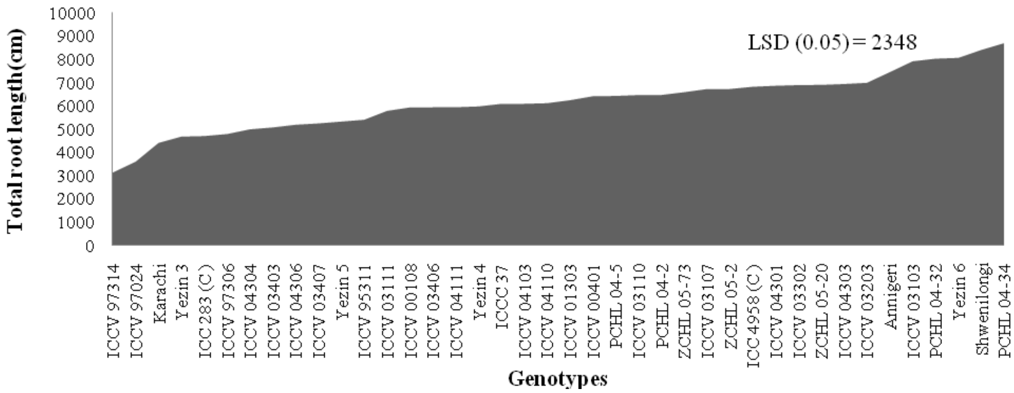


Figure 6.5. Total root length of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010

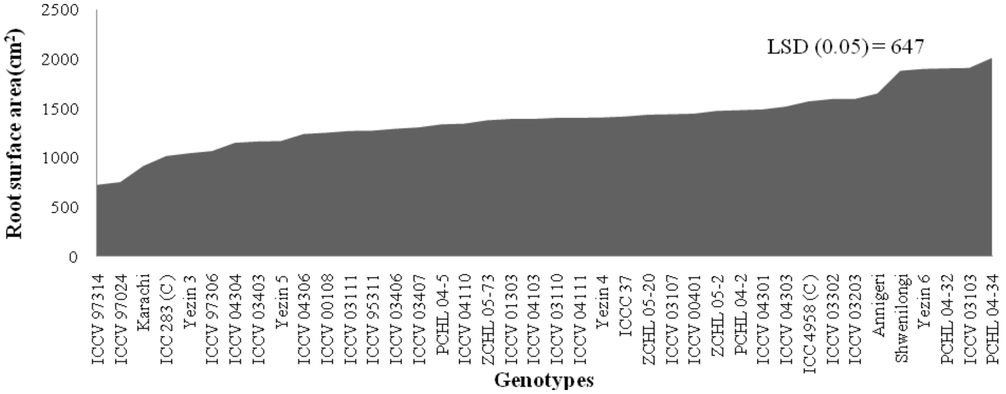


Figure 6.6. Root surface area of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010

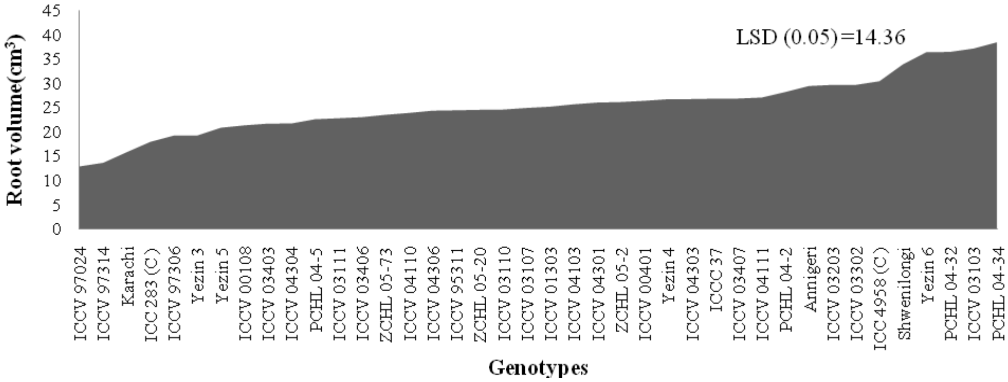


Figure 6.7. **Root volume of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010**

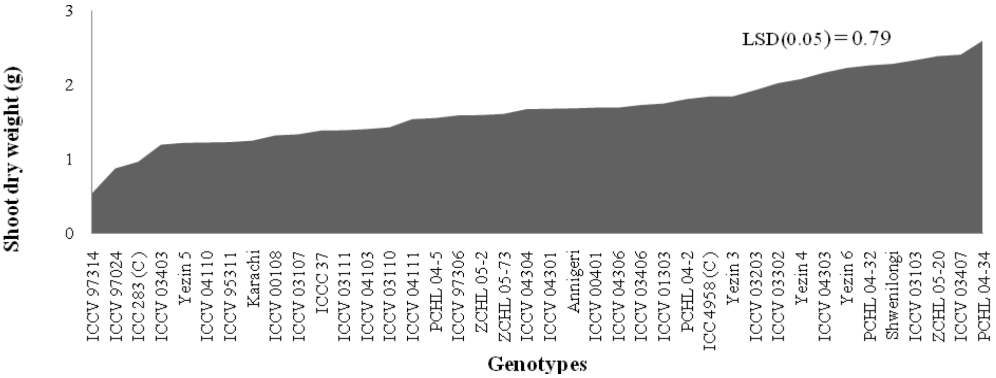


Figure 6.8. **Shoot dry weight of chickpea genotypes at 35 days after sowing at ICRISAT during post-monsoon season, 2009-2010**

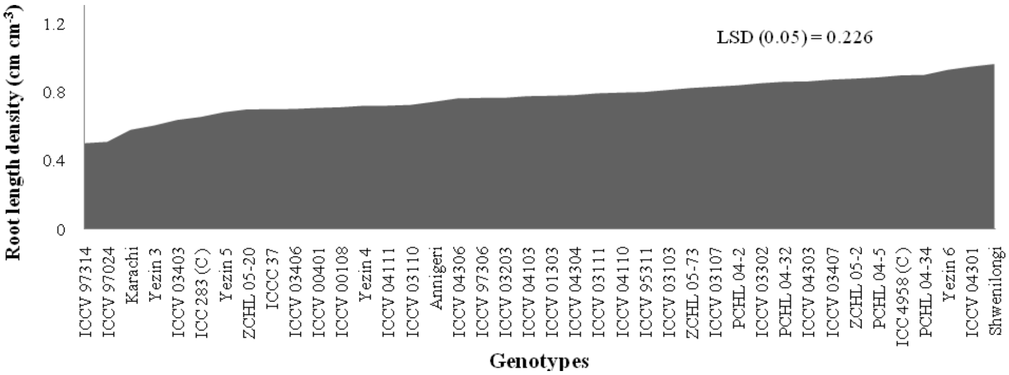


Figure 6.9. Root length density of chickpea genotypes at upper soil layer (0-60 cm) at ICRISAT during post-monsoon season, 2009-2010

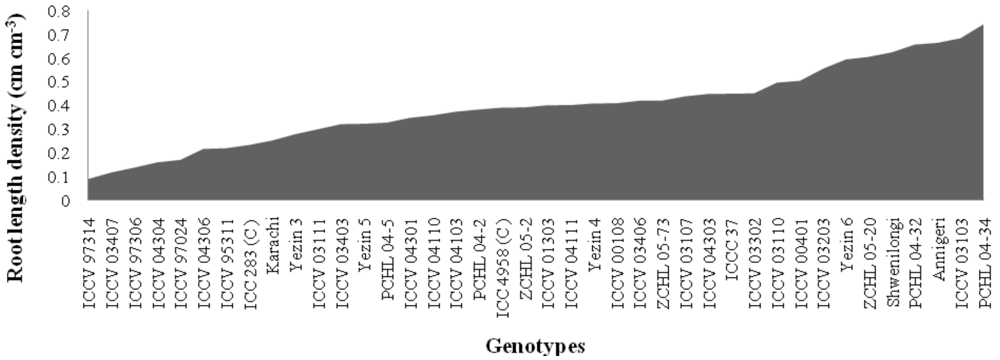


Figure 6.10. Root length density of chickpea genotypes at deeper soil layer (60-120 cm) at ICRISAT during post-monsoon season, 2009-2010

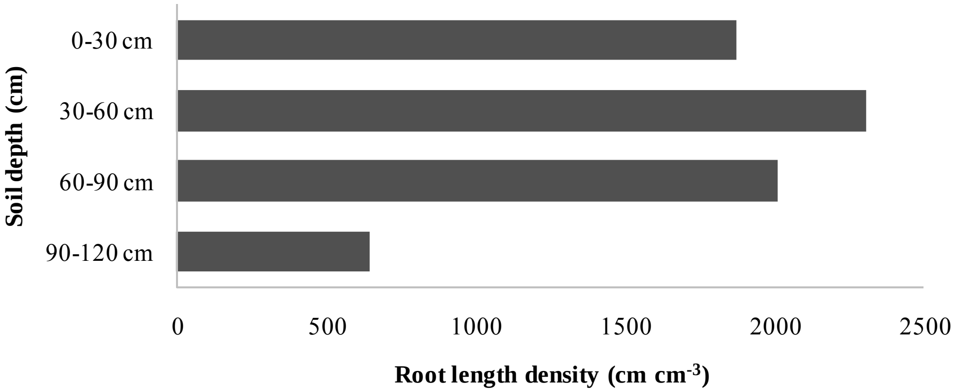


Figure 6.11. Mean root length density of chickpea genotypes over different soil depth at ICRISAT during post-monsoon season, 2009-2010

depths. Also RLD at all depths have been shown to positively contribute to the drought yields in chickpea (Krishnamurthy et al. 1996; Kashiwagi et al. 2005) and deep root systems in sorghum increased yield by 20% under drought conditions (Jordan et al. 1983).

An RLD of < 0.5 cm cm^{-3} in general (Passioura 1982), and < 0.4 cm cm^{-3} for chickpea in particular (Gregory 1988), has been suggested to be sub-optimal for complete extraction of soil moisture. The RLD data found in this study were in agreement with previous work where RLD in chickpea occasionally exceeds 0.5 cm cm^{-3} in a few soil layers even at later stages of crop growth when the maximum root growth has been attained such as 15 days before physiological maturity (Brown et al. 1989; Krishnamurthy et al. 1996; Yusuf Ali et al. 2002). However, under optimally irrigated conditions, RLD in some soil layers was > 0.5 cm cm^{-3} (Yusuf Ali et al. 2002).

6.3.10 Correlation coefficients among root traits

Correlation coefficients indicate the associations between pairs of the root traits were calculated under this study. All root parameters (root length density, root dry weight, rooting depth, total root length, root surface area and root volume) were positively and significantly associated each other with the high correlation coefficients values of 0.47 to 0.98 at $p < 0.001$ level (Table 6.2). In contrast, the R/TDM was weakly and negatively associated with all root traits. Shoot dry weight exhibited highly significant and positive association (0.47 to 0.79 at $p < 0.001$) with above all root traits.

In chickpea, favourable correlations among these three traits, RDp, RDW and RLD have been well documented (Krishnamurthy et al. 1996). Studies in groundnut also have described strong and favourable relationships between these traits and potential for simultaneous improvement, particularly with recurrent selection (Painawadee et al. 2009). The relationships of root parameters indicated that it was not necessary to evaluate all parameters and evaluation of the most convenient and less expensive characters would be sufficient. The RDp and RDW are more convenient for evaluation than other root parameters. In the present study, RDW was recommended to evaluate due to highly and linearly positive relationships with all root traits. Huang and Ketring (1987) also obtained highly positive linear correlation coefficients for root dry weight with root volume and total dry weight in peanut. High

Table 6.2. Correlation coefficients among the root traits of chickpea genotypes at ICRISAT during post-monsoon season, 2009-2010

Traits	RDp	RDW	RLD	R/TDM	TRL	RSA	RVol	SDW
RDp	-							
RDW	0.61***	-						
RLD	0.75***	0.88***						
R/TDM	0.01	0.03	-0.12	-				
TRL	0.75***	0.88***	0.81***	-0.12	-			
RSA	0.71***	0.91***	0.97***	-0.13	0.97***	-		
RVol	0.63***	0.91***	0.91***	-0.14	0.91***	0.98***	-	
SDW	0.47***	0.73***	0.73***	-0.63***	0.73***	0.78***	0.79***	-

*** Significant at the $p < 0.001$

RDp= Rooting depth (cm), RDW = Root dry weight (g), RLD = Root length density (cm cm^{-3}), R/TDM= Root dry weight/ whole plant dry weight, TRL = Total root length (cm), RSA=Root surface area (cm^2), RVol= Root volume (cm^3), SDW = Shoot dry weight (g) inter- relationships among root characters were also observed in pea (McGhee 2005) and common bean (Araujo et al. 2005). They also suggested that the high correlation between root mass and root area justifies screening genotypes based solely on root mass.

In addition, the SDW of tested genotypes showed strongly and positively associated with all root traits, and consistent with the findings of Krishnamurthy et al. (2003). This relation is very valuable for further root traits screening as it permits a less cumbersome preliminary selection of genotypes for large root mass on the basis of above ground shoot biomass or visual scores on shoot biomass. Compared to SDW, collecting RDW is time consuming. The negative and significant correlation between SDW and R/TDM also implied that drought tolerant genotypes tend to have higher SDW. Therefore, selection for vigorous growth can enhance for escaping terminal drought stress. On the basis of the International Center for Agricultural Research in the Dry Areas (ICARDA) recommendation, vigor score rated on 1-5 scale is subjective measurement, can serve as a rapid and concise estimation of drought tolerance.

Based on the ranking of genotypes for all root traits, PCHL 04-34, Shwenilonegi, ICCV 03103, Yezin 6 and PCHL 04-32 had consistently higher root length density, root dry weight, rooting depth, total root length, root surface area, root volume and shoot dry weight. Thus, the development of a good root system at this depth could contribute to drought resistance to some extent. Moreover, cylinder measurements showed good agreement with RDp and RLD determined in the field and have been used to explore the diversity for these traits in chickpea (Kashiwagi et al. 2006a). Therefore, the result of present study highlights the importance of roots in coping with terminal drought in chickpea.

6.4 Conclusion

A large genetic variability for root traits was observed among the 40 chickpea genotypes. In the present study, RDp, RDW and RLD were observed with good level of heritability, which may be explained by the presence of genetic variation of these traits among the tested chickpea genotypes. The PCHL 04-34, Shwenilonegi, ICCV 03103, Yezin 6 and PCHL 04-32 were identified as outstanding genotypes which possess prolific and deep root system. The shoot dry weight of the test genotypes showed strongly and positively associated with all root traits. This relation could be provided for further root traits screening because collecting the SDW is less time consuming compared to collecting the root traits. The information of the present study can be used as a valuable baseline for breeding programs of drought avoidance in chickpea.

CHAPTER VII

GENERAL DISCUSSION AND CONCLUSION

Conventional breeding for drought tolerance is primarily based on selection for yield and its components under a given drought stress environment. However, selection for yield is difficult because of high genotype x environment interaction (G x E). Because of the variability in drought pattern from year to year, trait-based selection could have an advantage. Trait-based breeding, however, requires trait dissection into components. Substantial efforts have targeted the manipulation of morpho-physiological traits influencing drought resistance through escape, avoidance and/or tolerance mechanisms. Both conventional and trait-based approaches have been used in breeding programmes for drought tolerance. After keen observation of the results of present study, the good performance on seed yield and the traits related to drought tolerance were selected for developing improved chickpea genotypes in drought tolerance.

7.1 Seed Yield

The adverse effect of moisture stress on seed yield was clearly evident by its mean value in the non-irrigated condition with a reduction in terms of 21 per cent at Zaloke Research Farm and 18 per cent at ICRISAT in comparison with irrigated condition (Section 4.3.1 and 5.3.1). Among the evaluated genotypes, there were significant variations in terms of seed yield and its attributes under non-irrigated and irrigated conditions. Based on the results of present study, high yielding genotypes were identified on ICCV 00108, ICCC 37 and ICCV 03107 at Sebin, while ICCC 37, PCHL 04-5, ICCV 95311 and ICCV 04110 had high seed yield under non-irrigated and irrigated conditions at Zaloke. At ICRISAT, however, PCHL 04-5, ICCV 03107, Annigeri and ICCV 00108 had high seed yield under non-irrigated condition, but not significantly different from that of check genotype ICC 4958. Under irrigated condition, ZCHL 05-2, Shwenilonegi, Annigeri and ICCV 03103 gave significantly high seed yield than ICC 4958. These high yielding genotypes are desi types, except ICCV 95311. Moreover, the relationships among chickpea yield and yield components are critical to utilizing these relationships effectively and developing desirable genotypes. Results showed that the number of pods per plant was positively and significantly correlated with seed yield at Sebin and ICRISAT experiments

(Section 3.3.2 and 5.3.2). In the selection of chickpea genotypes under non-irrigated condition for improving seed yield, number of pods per plant, therefore can be use as selection index.

7.2 Early Maturity

Early phenology (early flowering, early podding and early maturity) is the most important mechanism to escape terminal drought stress. The crops with early maturity, can avoid terminal drought by completing their cropping cycle before the drought stress becomes serious. The early-maturing varieties are preferred by most of the farmers because of a stable yield than the late-maturing varieties. The results of present study revealed that ICCV 97314, ZCHL 05-73 and ICCV 03406 were early maturity genotypes at Sebin. At Zaloke, the earliest matured genotype was ICCV 03403 and Yezin 4 under non-irrigated and irrigated conditions, respectively. Moreover, ICCV 97314, PCHL 04-32 and ICCV 01303 were observed earlier matured under both conditions as compared with other tested genotypes. At ICRISAT, Yezin 3 and Yezin 4 were observed the earliest maturing genotypes under both conditions and it was followed by ZCHL 05-73, PCHL 04-32 and ICCV 03406. These early maturity genotypes are kabuli types, except Yezin 4. In Myanmar, Yezin 3 and Yezin 4 (early maturity varieties) have greatly contributed to expansion of area and enhancement of productivity of chickpea in terminal drought-prone areas of central dry zone. The early maturing crop, however, may not give higher yield in more favorable season as it cannot accumulate enough total plant biomass due to reduced total photosynthetic period compared to the relatively longer maturing varieties.

7.3 Harvest Index

For grain crops, harvest index (HI) is the ratio of harvested grain to total shoot dry matter, and this can be used as a measure of reproductive efficiency. The results of present study revealed that ICCV 95311 gave the highest HI followed by ICCV 03203, PCHL 04-2 and Shwenilonegi under non-irrigated condition at Zaloke. Under irrigated condition, ICCV 01303 and ICCV 00401 were observed with the highest HI. At ICRISAT, the highest HI was observed on ZCHL 05-73 and ICCV 00108 under non-irrigated and irrigated conditions, respectively. However, ICCV 03203, ZCHL 05-2, Yezin 3, ICCV 00108 and ICCV 03302 gave HI of 0.57 and above under both conditions as compared to other tested genotypes, where high values of HI were associated with high seed yield (Section 5.3.2). More importantly, it maintained high values of HI above (0.50) in non-irrigated as well as irrigated condition at both Zalok and ICRISAT. Based on the results of this study, most genotypes with higher HI were observed as desi under non-irrigated whereas kabuli types under irrigated condition. The results of this study also supported that high HI and drought escape through early maturity could be assumed as important attributes in drought stressed different environmental conditions.

7.4 Drought Tolerance Indices

Many researchers introduced mathematical models as yield-based selection indices for identifying high seed yielding genotypes under drought condition. Based on the results of present study, drought tolerance indices such as Stress Tolerance Index (STI), Mean Productivity (MP) and Geometric Mean Productivity (GMP) indices have a similar ability to evaluate drought tolerant genotypes. Thus, selection based on the higher amounts of STI, MP and GMP could provided the genotypes, ICCC 37, ICCV 04110, PCHL 04-34, PCHL 04-5, and ICCV 95311 having high yield potential and tolerant to drought stress. Moreover, Tolerance Index (TOL) and Drought Susceptibility Index (DSI) gave similar results where TOL strongly correlated with DSI (Section 4.3.3), and so low quantity of TOL and DSI could be used to separate drought susceptible to moisture stress. Drought tolerance efficiency (DTE) was negatively associated with TOL and DSI and it indicated that high DTE led to fewer droughts sensitive. The present study revealed that Shwenilonegi, PCHL 04-34 and PCHL 04-2 had highest drought tolerance efficiency (99%), and least drought susceptibility index (-0.24 to 0.05) due to moisture stress (Section 4.3.2). Assessment of simple correlation coefficients among drought tolerance indices and seed yield of tested genotypes showed that STI, MP, and GMP enabled to identified genotypes having high potential yield and tolerant to drought stress and because of that were recognized as the best tolerance indices.

7.5 Traits Association with Drought Tolerance

In the present study, lower seed yield, larger SCMR, lower SLA and RWC indicated that non-irrigated condition suffered from more moisture stress to certain extent than irrigated condition. Chickpea genotypes showed different responses for traits associated with drought resistance. However, genotypes with good performance for traits associated with drought tolerance could be identified as drought tolerant genotypes. In addition, most of the drought tolerance traits in the present study had good heritability estimates, indicating that breeding progress could be achieved for these characters. Integrating these characters in chickpea breeding programs could increase drought tolerance in chickpea.

7.5.1 SPAD chlorophyll meter reading (SCMR)

Leaf photosynthesis is generally correlated with chlorophyll content per unit leaf area and hence the SPAD chlorophyll meter can provide a useful tool to screen for genotypic variation in potential photosynthetic capacity under drought conditions. The results of present study showed that the environmental mean value of SCMR under non-irrigated condition was significantly higher than under irrigated condition and so drought factor seemed to increase the value of SCMR. The genotypic differences for SCMR were observed at 60 and 75 DAS under non-irrigated and irrigated conditions (Section 5.3.3.1). The present study revealed that ICCV 00108 and ICCV 03110, which are desi types, showed superior and more consistent SCMR values than the others under both conditions at 60 and 75 DAS. The seed yields of these genotypes were high under non-irrigated condition of the present study. Thus, higher SCMR seems to be an indication of the genotype’s capacity for higher carbon assimilation and in turn seed yields even under moisture-limited situations. The identification and use of surrogate traits for SCMR are simple and useful as a selection criterion for drought tolerance in chickpea because of good heritability (Section 5.3.3.1).

7.5.2 Specific leaf area (SLA)

Low SLA indicated thicker leaves and hence potential for greater assimilate under drought stress. Low SLA, as a selection criterion for enhancing TE, could be an economically surrogate trait for drought tolerance. In the present study, genotypic differences for SLA were observed at 60 and 75 DAS under non-irrigated and irrigated conditions. The results of present study revealed that ICCV 01303, ICCV 03406, ICCV 04303, ICCV 04301 and ICCV 03302 were found to be consistently lower SLA than other genotypes under non-irrigated condition at 60 and 75 DAS. These selected genotypes (kabuli types) were also observed as promising in low SLA under irrigated condition at both sampling times (Section 5.3.3.2). Thus, low SLA seems to maintain better metabolic status of the source under stress to facilitate development of the pods.

7.5.3 Relative water content (RWC)

Mean values of leaf RWC less than 85% under non-irrigated condition have been indicated drought stress. In the present study, a higher degree of plant stress due to drought has been shown by decreased RWC at later crop growth (67.57 % at 60 DAS and 78.97 % at 75 DAS) under non-irrigated condition (Section 5.3.3.3). There was significant genotypic difference for RWC only at 75 DAS under both conditions. The result of present study showed that desi types genotypes: ICCC 37, Yezin 6 and Karachi had higher RWC under both conditions at 60 DAS. Although the highest RWC was found on ICCV 00108 under non-irrigated condition at 75 DAS, ICCC 37 and Yezin 6 were also promising genotypes for high RWC. The genotypes with a higher RWC also displayed a better seed yield under non-irrigated condition and higher in the number of pods per plant.

According to the results of present study, genotypes showed different responses for traits associated with drought tolerance and significantly correlated with SCMR and seed yield. The linear growth phase of the genotypes for SCMR, SLA and RWC was different leading to a crop growth stage x genotype interaction. Such interactions would create difficulties in identifying the best genotype for drought tolerance traits. Moreover, a significant linear correlation was observed for SCMR and SLA observations between at 60 and 75 DAS within the irrigated treatment. However, the results of present study suggested that 75 DAS of crop growth could be used as appropriate time of observations on SCMR and SLA (Section 5.3.4). This crop growth stage usually faces moisture deficit as a terminal drought. In the results of present study, significant interrelationships was observed between SCMR and SLA and SCMR, therefore could be used as a reliable and rapid measure to identify genotypes with low SLA in breeding and chickpea selection programmes.

7.6 Root Traits

Extensive and deep root systems have been recognized as one of the most important traits for improving chickpea productivity under progressively receding soil moisture condition. The results of present study revealed that a large genetic variability for root traits was observed among the tested chickpea genotypes. Among the root traits, root length density, root dry weight and rooting depth showed the largest genotypic variation with good levels of heritability (Section 6.3.1). The outstanding genotypes were identified with the best performance of root traits. Among them, kabuli types: PCHL 04-34, ICCV 01303 and PCHL 04-32 and desi types: Shwenilonegi and Yezin 6 were the most prolific and deep root system. The shoot dry weight of the test genotypes showed strongly and positively associated with all root traits. This relation could be provided for further root traits screening as it takes a less cumbersome selection of genotypes for different root traits on the basis of shoot dry weight. The finding of the present study can be used as a valuable baseline for breeding programs of drought avoidance in chickpea.

7.7 General conclusions

Establishing the importance of particular trait is very difficult and time consuming. The nature of abiotic stress (drought) is such that its timing and intensity is unpredictable from year to year. It also means that drought tolerance is a complex mechanism and can be achieved with the accumulation of favorable genes for traits important for higher productivity under drought stress. Various traits related to escape, avoidance or tolerance mechanisms can be considered depending upon the target environment.

Chickpea genotypes were significantly different for evaluated traits under non-irrigated and irrigated conditions, indicating that drought stress increased variation for these traits. Evaluated traits showed that five genotypes regarding high seed yield under non-irrigated (drought) were detected on ICCC 37 at Sebin and Zaloke, and PCHL 04-5, ICCV 03107, Annigeri and ICCV 00108 at ICRISAT while five genotypes were detected for HI on ICCV 03203, ZCHL 05-2, Yezin 3, ICCV 00108 and ICCV 03302 under both non-irrigated and irrigated conditions.

In addition to Yezin 3 and Yezin 4, early maturity on ICCV 97314, ZCHL 05-73 and ICCV 03406 at Sebin, and ICCV 97314 and PCHL 04-32 at Zaloke were detected. At ICRISAT, those selected genotypes also matured earlier than other tested genotypes. Based on the results of different selection indices, PCHL 04-34, ICCC 37, ICCV 04110, PCHL 04-2 and Shwenilonegi were rated as drought tolerant genotypes.

Traits associated with drought tolerance could be identified on ICCV 03110 and ICCV 00108 had high SCMR under non-irrigated condition, whereas ICCV 01303, ICCV 03406, ICCV 04303, ICCV 04301 and ICCV 03302 were good genotypes for SLA. The ICCC 37, Yezin 6, Karachi and ICCV 00108 were promising genotypes for RWC, while PCHL 04-32, Shwenilonegi, ICCV 03103, Yezin 6 and PCHL 04-32 had the most prolific and deep root systems. Differential responses of chickpea genotypes for these traits indicated that several drought resistance mechanisms might exist. Combining these characters in chickpea breeding programs should increase drought tolerance in chickpea. Therefore, it might be possible that those selected genotypes are drought tolerant. The assumption underlying the present study is that, once drought tolerant genotypes were identified, the drought tolerant genotypes should possess some root characters and/or morpho-physiological traits that are related to drought resistance. Moreover, these selected genotypes were observed as moderately resistance to soil borne diseases under the natural incidence.

In addition, different methods of selection for drought tolerance in chickpea could be used as following:

- Early flowering and early maturity with high harvest index are also important attributes for terminal season drought.
- Simple correlation among the studied traits with seed yield showed that there was significant and positive correlation between number of pods per plant and seed yield at Sebin and ICRISAT experiments. Thus, number of pods per plant could be used as selection index for improving seed yield.
- Drought tolerance indices such as STI, MP, and GMP with high value can differentiate the chickpea genotypes having high potential yield and tolerance to drought stress, whereas low value of TOL and DSI can separate the least drought susceptible genotypes to moisture stress.
- In addition, existing of the significant association between SCMR and seed yield and SLA at ICRISAT studies shows that the use of these traits can be beneficial in breeding programs. Based on these results, it can be concluded that SCMR, may be an appropriate trait for selecting genotypes with high yield potential.
- Identification of the high yielding chickpea genotypes with high SCMR and low SLA may be useful in breeding for tolerance to drought. The SPAD chlorophyll meter reading could be used as a reliable and rapid measure to identify genotypes

with low SLA or high SCMR which are surrogate measures of TE in drought research in crop improvement.

- As there were high inter-correlations among root parameters, evaluation of root dry weight alone is sufficient because it was more simple, economical and less time-consuming. Moreover, correlation between shoot dry weight and all root traits were significantly associated. A preliminary selection of genotypes for root traits could be evaluated on the basis of above ground shoot dry weight or visual scores on shoot biomass.

In conclusion, genotypes or cultivars can be developed or selected in Myanmar on the basis of growth vigor (biomass yield), early maturity, higher HI and SCMR under drought stress conditions. Nevertheless, the genotypes identified in this study for traits related to higher productivity under non-irrigated (drought stress) have important implications on accelerating the process of future breeding of adapted genotypes for drought prone areas.

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APPENDICES

Appendix 1. Mean monthly weather condition at Sebin Research Farm, Yamethin Township during post-monsoon season, 2008-2009

Months	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)
December	31.0	9.0	-
January	33.6	10.6	-
February	39.3	11.0	-
March	39.0	14.0	12.7
Mean	35.7	11.2	
Rainfall during monsoon month (from June to October)			736.6mm
Rainfall (10 years average)			850.9mm

Source: Sebin Research Farm, Annual report, 2009

Appendix 2. Mean monthly weather condition at Zaloke Research Farm, Monywa Township during post-monsoon season, 2009-2010

Months	Maximum Temperature (° C)	Minimum Temperature (° C)	Rainfall (mm)
November	34.9	21.4	-
December	34.5	19.5	-
January	32.9	16.1	-
February	30.6	12.2	-
March	-	-	-
Mean	33.6	18.2	-
Rainfall during monsoon months (June to October)			329.7 mm

Source: Zaloke Research Farm, Annual report, 2010

Appendix 3. Performance of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at Zaloke Research Farm during post-monsoon season, 2009-2010

Genotypes	Seed yield (kg ha^{-1})		Biomass (kg ha^{-1})		HI		Pods per plant	
	NI	I	NI	I	NI	I	NI	I
Annigeri	780	871	1411	2333	0.55	0.53	17	27
ICCC 37	1109	1282	2153	2507	0.51	0.51	34	37
ICCV 00108	741	1414	1405	2987	0.53	0.47	22	23
ICCV 00401	735	1024	1515	2041	0.49	0.50	22	28
ICCV 01303	669	832	1272	1680	0.53	0.50	22	28
ICCV 03103	1021	1179	1987	2169	0.51	0.56	21	22
ICCV 03107	647	735	1412	1413	0.46	0.52	18	32
ICCV 03110	777	1045	1500	2253	0.52	0.46	23	31
ICCV 03111	1009	1048	2032	1887	0.50	0.56	20	22
ICCV 03203	789	909	1591	1813	0.50	0.50	12	24
ICCV 03302	712	1026	1604	2038	0.47	0.52	19	28
ICCV 03403	713	837	1366	1545	0.52	0.54	23	24
ICCV 03406	762	994	1468	2323	0.52	0.53	20	20
ICCV 03407	565	944	1056	2333	0.54	0.52	27	39
ICCV 04103	660	954	1284	1751	0.51	0.54	23	26
ICCV 04110	1086	1294	2059	2436	0.53	0.53	21	46
ICCV 04111	873	1091	1614	3219	0.64	0.53	21	25
ICCV 04301	796	886	1525	2522	0.52	0.52	23	26
ICCV 04303	587	1058	1052	2451	0.57	0.49	22	29
ICCV 04304	835	986	1627	1938	0.51	0.51	17	22
ICCV 04306	946	989	1988	1857	0.49	0.53	26	30
ICCV 95311	1033	1299	2000	2499	0.52	0.52	22	26
ICCV 97024	631	730	1311	1373	0.48	0.53	18	27
ICCV 97306	870	1016	1854	1931	0.51	0.53	18	26
ICCV 97314	623	737	1141	1542	0.55	0.48	22	39
Karachi	715	977	1454	2107	0.51	0.53	22	22
PCHL 04-2	1102	1113	2146	2098	0.51	0.53	23	34
PCHL 04-32	929	1167	1779	2541	0.52	0.46	18	18
PCHL 04-34	1195	1183	2288	2346	0.52	0.52	13	32
PCHL 04-5	1028	1329	1847	3116	0.56	0.47	18	23
Shwenilonegi	841	801	1798	1573	0.47	0.51	31	32
Yezin 3	816	931	1236	1886	0.71	0.49	19	31
Yezin 4	616	974	1125	2136	0.55	0.46	12	27
Yezin 5	781	1308	1315	2672	0.66	0.49	15	39
Yezin 6	834	1094	1620	2042	0.51	0.54	17	22
ZCHL 05-2	536	793	780	1534	0.69	0.52	15	27
ZCHL 05-20	904	973	1838	1880	0.49	0.52	27	26
ZCHL 05-73	632	1003	1135	1835	0.56	0.55	17	31
ICC 4958 (C)	711	1056	1443	2008	0.49	0.53	16	23
Mean	811	1023	1565	2118	0.53	0.51	20	28
LSD$_{(0.05)}$	145	142	252	316	0.21	0.19	5.1	6.9

Appendix 3(Contd). Performance of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at Zaloke Research Farm during post-monsoon season, 2009-2010

Genotypes	Seeds per pod		100-seed wt.(g)		Canopy height (cm)		Days to maturity	
	NI	**I**	**NI**	**I**	**NI**	**I**	**NI**	**I**
Annigeri	1.2	1.3	20.8	20.3	27.3	32.3	88	88
ICCC 37	1.1	1.0	23.3	20.0	31.0	33.3	90	94
ICCV 00108	1.2	1.2	30.0	24.3	30.7	33.3	91	94
ICCV 00401	1.0	1.0	36.7	30.7	30.7	37.3	85	88
ICCV 01303	1.0	1.0	37.3	28.3	27.7	32.7	84	88
ICCV 03103	1.1	1.5	28.7	29.0	28.0	32.3	90	92
ICCV 03107	1.2	1.1	20.3	21.7	28.3	29.0	91	94
ICCV 03110	1.1	1.0	22.3	20.0	23.7	24.3	88	90
ICCV 03111	1.5	1.3	28.7	25.0	31.0	31.7	92	96
ICCV 03203	1.4	1.1	27.3	22.7	29.3	34.7	94	100
ICCV 03302	1.2	1.4	30.3	29.7	31.3	33.3	90	94
ICCV 03403	1.0	1.0	37.7	36.7	40.0	28.3	83	88
ICCV 03406	1.0	1.0	40.7	37.7	31.7	32.7	87	90
ICCV 03407	1.0	1.1	39.0	33.7	31.3	33.3	91	93
ICCV 04103	1.1	1.0	30.3	30.3	24.3	23.7	96	98
ICCV 04110	1.0	1.0	22.7	21.0	26.7	30.7	86	87
ICCV 04111	1.0	1.0	30.0	25.3	30.0	35.0	96	99
ICCV 04301	1.3	1.3	36.0	37.3	29.0	31.0	90	92
ICCV 04303	1.2	1.0	37.7	37.7	25.0	29.3	89	96
ICCV 04304	1.1	1.0	39.7	38.7	31.7	39.3	86	90
ICCV 04306	1.0	1.0	35.0	34.3	31.7	31.7	90	94
ICCV 95311	1.0	1.0	36.3	31.7	28.3	31.0	92	94
ICCV 97024	1.2	1.1	20.7	17.7	30.0	30.7	85	89
ICCV 97306	1.1	1.0	34.0	33.7	28.3	32.7	91	92
ICCV 97314	1.1	1.0	34.0	29.7	23.0	26.7	83	88
Karachi	1.0	1.0	17.0	16.7	31.7	33.3	89	93
PCHL 04-2	1.0	1.0	35.7	31.7	31.0	34.7	93	98
PCHL 04-32	1.2	1.1	33.7	25.0	29.0	29.7	84	86
PCHL 04-34	1.1	1.1	29.3	27.0	27.3	31.7	86	87
PCHL 04-5	1.2	1.5	25.0	23.5	32.3	34.0	86	99
Shwenilonegi	1.0	1.0	36.0	31.0	25.3	33.3	89	92
Yezin 3	1.0	1.0	22.0	24.8	30.5	33.0	86	86
Yezin 4	1.6	1.4	22.2	20.0	28.3	34.3	84	89
Yezin 5	1.1	1.0	27.5	26.3	34.5	35.5	93	93
Yezin 6	1.0	1.0	29.0	27.0	30.0	30.7	88	90
ZCHL 05-2	1.4	1.1	26.5	23.7	30.0	35.0	98	101
ZCHL 05-20	1.0	1.0	27.0	27.0	31.0	31.7	86	90
ZCHL 05-73	1.0	1.0	28.0	32.3	22.0	32.3	90	91
ICC 4958(C)	1.0	1.0	34.0	34.0	29.3	31.7	93	99
Mean	1.1	1.1	30.1	27.9	29.3	32.1	89	92
LSD$_{(0.05)}$	0.2	0.2	3.0	4.2	6.1	6.1	3.0	3.6

Appendix 4. Physicochemical properties of experimental soil at ICRISAT, Patancheru during post-monsoon season, 2009-2010

Properties	Value	Properties	Value
Field capacity (0.33 bar)	0.40	pH	8.31
Wilting point (15 bar)	0.29	Electrical conductivity (dSm^{-1})	0.18
Course sand (%)	7.44	Organic matter (%)	0.32
Find sand (%)	15.45	Available P (ppm)	1.40
Clay (%)	22.03	Available K (ppm)	111.00
Silt (%)	55.08	Available Zn (ppm)	0.60
Bulk density (g cm^{-3})	1.34	Exchangeable Ca (ppm)	6225.00

Source: Analysis at Soil Laboratory, ICRISAT

Appendix 5. Mean monthly weather condition at ICRISAT, Patancheru during post-monsoon season, 2009-2010

Months	Maximum Temperature (°C)	Minimum Temperature (°C)	Pan evaporation (mm)	Rainfall (mm)
November	29.3	18.3	4.1	44.2
December	28.0	13.9	3.6	7.4
January	27.7	14.3	3.6	39.0
February	32.2	16.8	5.9	3.0
Mean	29.6	16.5	4.3	-
Rainfall during monsoon months (June to October)				901.7 mm

Source: Meteorological Unit, ICRISAT

Appendix 6. Performance of morphological traits of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Genotypes	Seed yield (kg ha^{-1})		Biomass (kg ha^{-1})		HI	
	NI	I	NI	I	NI	I
Annigeri	2854	3464	4662	7545	0.59	0.47
ICCC 37	2082	3118	3368	6357	0.61	0.48
ICCV 00108	2715	2968	4730	4574	0.57	0.65
ICCV 00401	2031	2939	3818	5708	0.51	0.51
ICCV 01303	2500	2225	4562	5030	0.53	0.43
ICCV 03103	1735	3444	3114	7773	0.55	0.43
ICCV 03107	2905	2457	5463	4808	0.53	0.53
ICCV 03110	2609	2759	4298	5742	0.60	0.48
ICCV 03111	2368	2589	3921	5030	0.60	0.54
ICCV 03203	2158	3361	3778	5973	0.60	0.55
ICCV 03302	1881	2632	3234	4833	0.57	0.56
ICCV 03403	2264	2373	4379	5789	0.52	0.42
ICCV 03406	1351	2989	2633	6147	0.54	0.48
ICCV 03407	2584	2426	4862	5428	0.52	0.45
ICCV 04103	2658	3348	4876	7580	0.56	0.44
ICCV 04110	2119	2596	3688	5398	0.58	0.49
ICCV 04111	1917	2726	4278	5644	0.45	0.48
ICCV 04301	1472	2043	3244	5114	0.50	0.41
ICCV 04303	1726	2884	3324	5984	0.52	0.47
ICCV 04304	2158	2793	4813	6251	0.43	0.46
ICCV 04306	2542	3202	4186	6980	0.59	0.46
ICCV 95311	1787	2650	3462	7473	0.53	0.35
ICCV 97024	1951	2512	3260	5582	0.57	0.46
ICCV 97306	2484	2510	4753	5505	0.51	0.46
ICCV 97314	2193	2709	3851	5544	0.61	0.49
Karachi	2242	1894	4351	4091	0.51	0.48
PCHL 04-2	2391	2326	4398	5214	0.56	0.46
PCHL 04-32	2271	2668	4193	5649	0.53	0.47
PCHL 04-34	2600	2400	4716	4871	0.56	0.48
PCHL 04-5	2985	2611	5082	6158	0.57	0.43
Shwenilonegi	2129	3605	3794	7295	0.57	0.49
Yezin 3	1918	2754	3372	4356	0.58	0.64
Yezin 4	2119	2731	3785	4846	0.54	0.55
Yezin 5	1631	1578	2900	3320	0.55	0.50
Yezin 6	2082	2966	3727	5884	0.57	0.49
ZCHL 05-2	2616	3701	4638	6498	0.60	0.57
ZCHL 05-20	2164	2807	4205	5253	0.50	0.52
ZCHL 05-73	2341	2003	3102	4404	0.74	0.45
ICC 4958 (C)	2675	2526	5389	4862	0.53	0.55
Mean	2236	2725	4057	5654	0.55	0.49
LSD$_{(0.05)}$	748	844	1396	1600	0.12	0.10

Appendix 6(Contd.). Performance of morphological traits of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Genotypes	Days to maturity		Canopy height (cm)		Pods per plant	
	NI	I	NI	I	NI	I
Annigeri	95	103	15.6	39.0	59	47
ICCC 37	91	102	26.2	37.7	58	54
ICCV 00108	89	97	29.3	41.2	47	49
ICCV 00401	88	98	31.5	48.5	36	45
ICCV 01303	89	102	32.2	40.9	38	24
ICCV 03103	92	102	30.0	39.9	34	81
ICCV 03107	89	100	36.8	42.3	56	87
ICCV 03110	89	102	30.5	39.2	56	79
ICCV 03111	92	101	30.5	32.8	49	44
ICCV 03203	89	98	32.6	41.4	39	57
ICCV 03302	89	101	30.2	38.9	41	43
ICCV 03403	91	105	33.8	41.3	39	49
ICCV 03406	84	98	29.9	37.4	46	38
ICCV 03407	91	102	33.8	37.7	33	32
ICCV 04103	94	104	37.5	48.4	53	69
ICCV 04110	89	107	29.5	42.3	69	66
ICCV 04111	93	106	32.5	44.3	35	55
ICCV 04301	90	103	33.2	43.1	36	34
ICCV 04303	91	98	33.5	44.2	27	41
ICCV 04304	90	102	33.3	43.3	37	35
ICCV 04306	92	105	34.5	45.3	40	30
ICCV 95311	93	105	31.3	42.5	36	46
ICCV 97024	96	106	26.0	37.2	41	66
ICCV 97306	95	108	30.2	38.8	35	38
ICCV 97314	89	101	30.2	39.3	38	58
Karachi	91	104	30.8	36.8	56	66
PCHL 04-2	92	105	30.2	41.1	39	39
PCHL 04-32	86	97	32.7	39.0	37	50
PCHL 04-34	86	98	33.3	35.6	42	59
PCHL 04-5	91	106	31.1	39.8	66	66
Shwenilonegi	89	104	31.8	42.2	37	41
Yezin 3	83	94	25.9	30.0	45	51
Yezin 4	83	96	28.3	38.9	41	63
Yezin 5	92	96	31.7	35.2	46	67
Yezin 6	85	101	30.7	39.6	53	47
ZCHL 05-2	91	100	29.7	40.8	24	63
ZCHL 05-20	87	101	30.8	41.2	46	50
ZCHL 05-73	84	97	29.3	37.0	27	66
ICC 4958 (C)	96	107	35.9	42.7	43	43
Mean	90.0	101.6	31.2	40.2	43.0	52.2
LSD$_{(0.05)}$	5.3	4.2	4.5	4.1	19.8	24.6

Appendix 6(Contd.). Performance of morphological traits of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Genotypes	Seeds per pod		100-seed weight (g)		Harvested plants (1m)	
	NI	I	NI	I	NI	I
Annigeri	1.1	1.0	24.08	26.23	12	11
ICCC 37	1.2	1.2	23.22	21.68	12	11
ICCV 00108	1.1	1.4	29.14	28.49	12	12
ICCV 00401	1.0	1.0	31.02	34.10	12	12
ICCV 01303	1.0	1.0	36.54	28.10	13	11
ICCV 03103	1.2	1.3	25.59	30.02	11	11
ICCV 03107	1.1	1.2	21.73	21.65	13	11
ICCV 03110	1.0	1.1	23.53	23.14	13	11
ICCV 03111	1.3	1.3	27.94	27.39	12	12
ICCV 03203	1.2	1.2	27.32	28.77	13	13
ICCV 03302	1.0	1.0	30.13	35.12	11	12
ICCV 03403	1.0	1.0	35.39	37.39	14	13
ICCV 03406	1.0	1.0	39.80	34.99	14	11
ICCV 03407	1.0	1.0	39.64	40.26	14	13
ICCV 04103	1.2	1.0	30.23	28.73	15	12
ICCV 04110	1.0	1.0	21.21	22.60	14	11
ICCV 04111	1.2	1.2	33.62	26.56	13	11
ICCV 04301	1.0	1.0	44.83	38.74	12	14
ICCV 04303	1.0	1.0	39.17	40.32	12	12
ICCV 04304	1.0	1.0	38.94	37.81	15	14
ICCV 04306	1.0	1.1	41.27	42.63	10	12
ICCV 95311	1.0	1.0	31.64	33.46	12	12
ICCV 97024	1.3	1.1	22.98	18.95	12	13
ICCV 97306	1.0	1.0	34.79	36.17	12	11
ICCV 97314	1.0	1.0	35.48	34.20	13	12
Karachi	1.1	1.2	16.48	16.40	14	12
PCHL 04-2	1.0	1.0	35.20	31.86	13	12
PCHL 04-32	1.1	1.0	28.25	32.85	12	11
PCHL 04-34	1.0	1.0	30.79	32.78	13	12
PCHL 04-5	1.4	1.3	25.33	23.54	14	13
Shwenilonegi	1.0	1.0	35.60	38.23	11	12
Yezin 3	1.0	1.0	26.52	19.86	13	12
Yezin 4	1.3	1.3	21.14	22.92	12	12
Yezin 5	1.0	1.0	24.48	27.88	13	12
Yezin 6	1.0	1.0	27.56	25.93	12	13
ZCHL 05-2	1.3	1.4	24.97	24.49	12	14
ZCHL 05-20	1.0	1.0	27.05	27.88	13	12
ZCHL 05-73	1.0	1.4	28.43	19.91	12	13
ICC 4958 (C)	1.0	1.0	38.51	31.14	11	12
Mean	1.1	1.1	30.24	29.57	12.4	12.0
$LSD_{(0.05)}$	0.1	0.1	5.77	5.69	2.8	2.5

Appendix 7. Performance of physiological trait (SCMR) of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Genotypes	SPAD Chlorophyll Meter Reading (SCMR)						
	45 DAS		60 DAS		75 DAS		90 DAS
	NI	I	NI	I	NI	I	I
Annigeri	61.79	60.29	65.25	55.32	65.49	58.92	67.03
ICCC 37	63.19	63.67	70.68	56.48	67.08	58.12	70.28
ICCV 00108	62.60	62.87	71.36	61.74	69.05	66.78	71.38
ICCV 00401	61.65	59.08	66.96	51.68	62.11	60.19	67.20
ICCV 01303	60.39	58.96	66.76	59.18	63.33	60.80	67.22
ICCV 03103	61.92	58.44	66.91	52.76	66.06	57.34	61.35
ICCV 03107	57.37	56.34	63.12	50.62	63.27	56.02	67.05
ICCV 03110	63.58	63.03	69.83	58.33	70.07	65.03	65.72
ICCV 03111	61.17	60.58	66.98	55.35	67.21	59.88	71.05
ICCV 03203	59.87	58.31	66.23	52.09	67.31	62.22	65.33
ICCV 03302	59.48	59.02	68.21	58.08	63.42	63.14	61.66
ICCV 03403	61.69	60.83	65.32	54.17	65.32	61.29	61.75
ICCV 03406	60.88	61.31	69.87	57.83	62.01	61.10	63.57
ICCV 03407	60.90	58.68	66.47	53.48	65.21	63.50	64.02
ICCV 04103	58.59	58.40	67.43	52.77	65.40	59.96	64.41
ICCV 04110	62.07	61.53	69.87	58.62	67.41	63.39	64.26
ICCV 04111	60.03	57.38	65.01	52.38	66.24	60.08	65.48
ICCV 04301	63.09	58.68	67.16	53.92	64.15	61.40	66.45
ICCV 04303	60.85	59.55	67.68	53.03	63.39	59.69	71.19
ICCV 04304	61.39	56.17	66.49	49.33	62.74	57.05	66.65
ICCV 04306	61.21	60.91	65.82	53.73	64.13	64.49	69.23
ICCV 95311	60.83	59.74	67.37	52.45	64.11	58.35	65.19
ICCV 97024	62.03	63.05	64.08	56.17	66.11	60.88	68.59
ICCV 97306	61.19	59.78	67.29	51.67	65.86	57.38	65.30
ICCV 97314	63.00	61.26	67.24	56.23	66.41	59.25	66.45
Karachi	62.41	58.08	65.51	56.31	65.64	57.70	67.80
PCHL 04-2	59.87	58.90	65.98	53.99	68.03	61.16	68.39
PCHL 04-32	61.11	60.30	67.64	58.12	62.60	61.55	61.97
PCHL 04-34	61.40	60.92	70.42	55.82	62.43	56.49	63.43
PCHL 04-5	61.94	61.22	67.30	51.64	66.08	60.26	65.91
Shwenilonegi	57.92	59.40	66.91	52.19	67.30	60.05	70.02
Yezin 3	59.94	58.24	67.69	56.39	59.85	57.00	70.25
Yezin 4	59.74	58.18	67.72	57.92	63.01	59.93	71.23
Yezin 5	57.68	57.94	63.65	56.14	61.03	57.52	72.73
Yezin 6	61.17	59.79	67.32	56.90	66.56	60.92	65.66
ZCHL 05-2	62.33	60.66	65.27	52.11	66.42	60.72	64.84
ZCHL 05-20	61.32	58.89	67.51	57.27	66.16	62.20	66.35
ZCHL 05-73	59.19	56.30	65.02	55.59	57.99	58.23	64.34
ICC 4958(C)	59.52	59.03	65.84	54.63	68.15	62.28	64.48
Mean	60.93	59.63	67.00	54.93	64.98	60.32	66.54
$LSD_{(0.05)}$	3.32	3.00	2.71	3.42	3.85	4.14	7.56

Appendix 8. Performance of physiological trait (SLA) of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

Genotypes	Specific Leaf Area (SLA)						
	45 DAS		60 DAS		75 DAS		90 DAS
	NI	I	NI	I	NI	I	I
Annigeri	213.9	259.7	267.1	272.0	291.5	306.3	139.4
ICCC 37	207.8	228.7	192.0	257.2	243.1	287.3	144.0
ICCV 00108	315.6	251.1	178.2	240.8	186.4	205.9	152.2
ICCV 00401	180.5	261.0	182.4	278.5	194.8	236.6	156.5
ICCV 01303	217.8	231.9	142.1	207.4	160.3	207.0	130.4
ICCV 03103	249.5	238.5	201.7	246.8	182.4	234.6	160.8
ICCV 03107	282.5	308.7	232.1	280.0	227.5	261.1	110.9
ICCV 03110	216.4	262.4	185.5	283.5	267.9	271.3	102.7
ICCV 03111	225.3	234.4	192.9	228.2	215.7	232.2	126.0
ICCV 03203	259.4	277.2	203.7	247.6	176.0	201.5	164.4
ICCV 03302	243.0	288.3	163.6	196.2	157.0	217.8	149.5
ICCV 03403	202.7	290.5	199.8	238.1	257.3	218.2	137.2
ICCV 03406	272.8	247.4	157.5	193.1	175.6	192.8	171.9
ICCV 03407	214.7	251.7	162.6	228.2	221.9	193.6	137.7
ICCV 04103	225.9	277.4	194.8	212.7	216.9	247.4	148.9
ICCV 04110	251.5	221.7	175.7	252.7	183.8	260.7	199.2
ICCV 04111	229.2	241.9	190.2	269.5	172.3	254.5	136.0
ICCV 04301	266.4	223.4	163.0	221.8	158.1	216.5	160.0
ICCV 04303	243.8	273.0	159.3	236.8	150.8	200.9	156.6
ICCV 04304	220.6	239.9	187.5	239.4	228.1	216.2	146.1
ICCV 04306	244.0	261.0	172.3	235.5	172.4	193.7	146.4
ICCV 95311	288.0	259.9	228.8	255.7	252.2	271.3	146.8
ICCV 97024	218.2	232.8	235.3	298.3	273.7	282.6	157.9
ICCV 97306	181.7	267.3	210.1	240.4	223.8	252.5	183.7
ICCV 97314	239.9	223.8	182.6	274.8	197.5	204.5	156.3
Karachi	226.9	240.5	239.8	263.8	228.3	236.8	137.4
PCHL 04-2	228.0	249.4	220.7	277.0	173.9	244.6	157.7
PCHL 04-32	196.5	290.0	195.3	233.8	194.0	188.8	186.8
PCHL 04-34	242.6	241.7	173.6	207.5	212.1	201.7	169.2
PCHL 04-5	339.1	268.4	182.5	252.7	185.1	267.7	156.4
Shwenilonegi	190.0	243.6	220.9	235.0	214.3	217.0	132.0
Yezin 3	217.9	256.5	187.5	220.7	189.1	238.6	141.3
Yezin 4	202.9	244.5	179.0	218.6	259.3	221.5	173.1
Yezin 5	200.2	241.3	219.0	205.2	232.0	185.3	209.7
Yezin 6	268.8	251.2	212.0	215.6	184.9	258.7	169.3
ZCHL 05-2	178.6	231.4	204.6	246.6	249.7	267.7	153.4
ZCHL 05-20	277.9	263.7	347.2	273.0	226.5	218.1	137.3
ZCHL 05-73	239.4	251.1	166.0	247.5	196.2	211.3	170.4
ICC 4958(C)	222.5	239.9	195.3	227.4	209.7	229.9	138.9
Mean	234.4	253.0	197.5	242.5	208.8	232.2	152.7
LSD$_{(0.05)}$	50.6	57.8	36.2	42.6	50.5	48.7	70.6

Appendix 9. Performance of physiological trait (RWC) of chickpea genotypes under non-irrigated (NI) and irrigated (I) conditions at ICRISAT during post-monsoon season, 2009-2010

	Relative Leaf Water Content (RWC)						
Genotypes	**45 DAS**		**60 DAS**		**75 DAS**		**90 DAS**
	NI	**I**	**NI**	**I**	**NI**	**I**	**I**
Annigeri	72.31	88.58	66.44	73.72	75.40	93.19	71.36
ICCC 37	82.56	88.44	78.31	79.37	84.92	82.92	67.71
ICCV 00108	81.03	87.67	66.73	67.26	86.03	80.89	57.41
ICCV 00401	78.88	83.91	65.29	68.31	72.65	89.19	59.18
ICCV 01303	84.19	85.76	66.78	72.61	81.22	79.65	70.88
ICCV 03103	78.46	82.01	64.27	82.97	80.05	83.15	72.58
ICCV 03107	81.29	90.83	64.95	74.20	76.68	72.62	86.29
ICCV 03110	85.35	94.16	70.95	80.33	80.06	78.80	65.86
ICCV 03111	80.50	81.23	67.39	65.48	77.76	73.01	68.35
ICCV 03203	81.19	87.43	65.43	75.34	75.88	80.28	72.51
ICCV 03302	73.04	83.86	65.91	74.50	77.55	88.72	70.90
ICCV 03403	67.99	82.66	66.67	78.50	80.33	75.28	67.61
ICCV 03406	83.05	79.54	61.39	82.44	76.22	76.67	69.01
ICCV 03407	86.64	90.27	68.74	72.71	76.46	80.71	69.99
ICCV 04103	80.32	87.12	67.90	78.27	70.69	77.00	68.48
ICCV 04110	83.39	91.27	66.22	79.44	78.79	82.04	61.10
ICCV 04111	84.80	90.13	68.45	65.01	73.23	70.90	69.56
ICCV 04301	76.37	87.75	67.61	73.45	82.19	80.89	66.46
ICCV 04303	79.38	89.62	63.96	71.04	77.30	95.85	70.86
ICCV 04304	82.89	80.30	66.43	73.17	83.45	81.01	60.07
ICCV 04306	83.45	81.82	61.36	79.62	80.53	87.41	70.16
ICCV 95311	81.86	84.82	71.09	74.11	69.66	78.99	66.54
ICCV 97024	70.27	84.77	63.49	74.77	79.96	84.16	72.46
ICCV 97306	80.85	89.59	65.69	78.62	77.86	85.21	75.81
ICCV 97314	78.70	92.36	67.88	73.57	80.75	85.87	67.40
Karachi	78.89	91.90	71.58	86.40	80.49	81.00	73.59
PCHL 04-2	79.73	88.93	71.58	68.16	78.12	82.88	72.14
PCHL 04-32	81.02	88.98	66.92	83.24	82.42	79.51	70.60
PCHL 04-34	83.66	92.26	68.07	80.48	76.97	86.19	72.21
PCHL 04-5	81.16	88.14	69.03	75.06	79.86	78.88	69.35
Shwenilonegi	79.66	88.17	70.59	76.68	81.97	76.01	69.95
Yezin 3	78.45	90.38	69.44	77.97	80.05	76.70	70.87
Yezin 4	79.48	89.68	66.31	80.26	75.99	82.92	69.57
Yezin 5	79.19	85.56	70.32	74.13	85.61	81.03	61.16
Yezin 6	80.69	89.00	73.91	80.97	85.84	82.00	74.61
ZCHL 05-2	78.21	91.13	66.08	80.42	78.93	78.08	71.85
ZCHL 05-20	83.62	92.24	71.74	79.29	81.36	80.23	70.11
ZCHL 05-73	80.78	86.14	65.32	77.69	81.99	86.83	70.56
ICC 4958(C)	79.89	86.88	65.06	82.49	74.47	79.51	75.79
Mean	80.08	87.57	67.57	76.21	78.97	81.44	69.51
LSD$_{(0.05)}$	9.60	9.27	8.95	7.72	7.17	10.08	13.45

Appendix 10. Performance of root traits of chickpea genotypes at ICRISAT during post-monsoon season, 2009-2010

Genotypes	RDp	RDW	RLD	R/TDM	TRL	RSA	RVol	SDW
Annigeri	95.0	0.94	0.390	0.36	7459	1652	29.42	1.68
ICCC 37	92.0	0.78	0.324	0.36	6096	1419	26.81	1.38
ICCV 00108	95.5	0.67	0.315	0.34	5944	1255	21.29	1.32
ICCV 00401	105.0	0.89	0.302	0.35	6423	1448	26.36	1.69
ICCV 01303	94.5	0.80	0.329	0.31	6253	1394	25.16	1.75
ICCV 03103	103.0	1.14	0.382	0.33	7923	1911	37.16	2.33
ICCV 03107	86.5	0.87	0.385	0.40	6733	1442	24.89	1.33
ICCV 03110	98.5	0.93	0.329	0.40	6476	1405	24.56	1.43
ICCV 03111	90.5	0.83	0.319	0.39	5795	1273	22.77	1.39
ICCV 03203	110.5	0.98	0.317	0.33	7001	1596	29.65	1.93
ICCV 03302	95.5	1.02	0.362	0.33	6904	1596	29.66	2.02
ICCV 03403	97.5	0.74	0.250	0.39	5085	1166	21.66	1.19
ICCV 03406	104.0	0.94	0.283	0.35	5948	1295	22.99	1.73
ICCV 03407	68.5	0.93	0.378	0.28	5256	1309	26.83	2.41
ICCV 04103	87.5	0.86	0.344	0.37	6098	1395	25.64	1.40
ICCV 04110	100.0	0.80	0.307	0.42	6125	1347	23.86	1.22
ICCV 04111	97.5	0.85	0.302	0.39	5951	1406	27.05	1.54
ICCV 04301	76.5	0.93	0.446	0.36	6873	1491	26.00	1.68
ICCV 04303	93.0	0.88	0.374	0.29	6948	1519	26.72	2.16
ICCV 04304	72.5	0.73	0.349	0.31	5003	1153	21.68	1.67
ICCV 04306	72.0	0.95	0.350	0.36	5199	1242	24.32	1.69
ICCV 95311	83.5	0.91	0.322	0.45	5412	1276	24.41	1.23
ICCV 97024	74.0	0.50	0.228	0.36	3614	755	12.83	0.87
ICCV 97306	75.5	0.72	0.316	0.33	4799	1069	19.19	1.59
ICCV 97314	75.0	0.37	0.209	0.40	3145	727	13.58	0.54
Karachi	86.0	0.56	0.251	0.32	4418	917	15.77	1.25
PCHL 04-2	85.0	0.99	0.376	0.36	6479	1483	28.18	1.81
PCHL 04-32	94.0	1.34	0.425	0.37	8038	1907	36.46	2.26
PCHL 04-34	113.0	1.43	0.383	0.35	8701	2012	38.44	2.60
PCHL 04-5	95.0	0.91	0.336	0.39	6437	1340	22.56	1.55
Shwenilonegi	108.5	1.33	0.405	0.37	8411	1882	33.89	2.28
Yezin 3	87.5	0.77	0.265	0.29	4689	1047	19.21	1.84
Yezin 4	90.0	0.96	0.331	0.32	5987	1409	26.70	2.08
Yezin 5	86.5	0.84	0.303	0.42	5334	1171	20.81	1.22
Yezin 6	96.5	1.14	0.416	0.34	8073	1901	36.41	2.23
ZCHL 05-2	90.5	0.96	0.370	0.37	6736	1476	26.11	1.59
ZCHL 05-20	99.5	0.92	0.333	0.26	6913	1437	24.51	2.39
ZCHL 05-73	89.0	0.84	0.351	0.34	6597	1381	23.47	1.61
ICC 4958(C)	88.5	1.17	0.384	0.39	6831	1572	30.41	1.84
ICC 283(C)	80.0	0.61	0.292	0.40	4714	1019	17.90	0.96
Mean	90.8	0.89	0.336	0.36	6171	1387	25.38	1.67
LSD $_{(0.05)}$	21.9	0.40	0.094	0.09	2348	647	14.36	0.79

RDp= Rooting depth (cm), RDW = Root dry weight (g), RLD = Root length density (cm cm^{-3}), R/TDM= Root dry weight/ whole plant dry weight, TRL = Total root length (cm), RSA=Root surface area (cm^{2}), RVol= Root volume (cm^{3}), SDW = Shoot dry weight (g)

Appendix 11. Root length density (cm cm^{-3}) at upper and deeper soil layer of chickpea genotypes at ICRISAT during post-monsoon season, 2009 - 2010

Genotypes	Upper soil layer(0-60 cm)	Deeper soil layer (60-120 cm)
Annigeri	0.745	0.663
ICCC 37	0.701	0.449
ICCV 00108	0.713	0.409
ICCV 00401	0.709	0.504
ICCV 01303	0.779	0.401
ICCV 03103	0.813	0.682
ICCV 03107	0.833	0.438
ICCV 03110	0.726	0.496
ICCV 03111	0.794	0.300
ICCV 03203	0.767	0.554
ICCV 03302	0.852	0.451
ICCV 03403	0.638	0.321
ICCV 03406	0.703	0.420
ICCV 03407	0.874	0.118
ICCV 04103	0.777	0.374
ICCV 04110	0.798	0.358
ICCV 04111	0.722	0.401
ICCV 04301	0.949	0.348
ICCV 04303	0.863	0.448
ICCV 04304	0.783	0.161
ICCV 04306	0.764	0.217
ICCV 95311	0.801	0.220
ICCV 97024	0.511	0.171
ICCV 97306	0.767	0.139
ICCV 97314	0.503	0.091
Karachi	0.581	0.253
PCHL 04-2	0.840	0.383
PCHL 04-32	0.861	0.656
PCHL 04-34	0.901	0.741
PCHL 04-5	0.887	0.328
Shwenilonegi	0.964	0.623
Yezin 3	0.606	0.279
Yezin 4	0.722	0.408
Yezin 5	0.684	0.323
Yezin 6	0.931	0.593
ZCHL 05-2	0.879	0.392
ZCHL 05-20	0.700	0.604
ZCHL 05-73	0.825	0.421
ICC 4958(C)	0.899	0.391
ICC 283(C)	0.656	0.234
Mean	0.771	0.394
LSD $_{(0.05)}$	0.226	-