INTRODUCTION

Burgeoning global human population and a decline in crop produce-quantity and -quality are putting heavy pressure on the ability of agriculture to feed mankind and meet their nutritional demands, especially in the developing countries. Moreover, rapid urbanization and industrialization are resulting into severe decline in agricultural land. Hence, it is obvious that the global food security issue will go grim. In this perspective, increasing and intensifying the agricultural areas to increase crop production seem the only solution. However, opportunities are being extensively explored to get sustainably more crop produce from the limited agricultural areas. It is worth mentioning that the non-availability of crop nutrients in appropriate amount and form to crops (Hussain et al., 2006), along with a lack of concern for plant genotypes having high tolerance of nutrient deficiencies or toxicities (Malakouti and Balali, 2004), is a major constraint in the way of achieving the desired yield to sustain population growth. To the other side, adequate and regular intake of protein, which supplies the building blocks - amino acids - to the human/animal body. In this perspective, edible legume grains are a major dietary source of proteins and also form an integral component of sustainable agricultural and food security, apart from providing high quality livestock feed, seeds, green manure, and soil cover. Hence in order to meet the nutritional-food demand of the fast-growing population, we ought to draw heavily from high quality crops.

Chickpea (Cicer arietinum L.) is a third most important food legume; and worldwide, it is being cultivated in approximately 11 m ha with an annual produce of 9 million ton in more than 50 countries. It is a cheap source of high quality protein in the diet of millions of people in developing countries, who cannot afford animal protein for balanced nutrition, and hence can play an important role in overcoming problems related to nutritional insecurity of the poor in the developing countries. In the developed countries, consumers consider C. arietinum as a health food (Zia Ul-Haq et al., 2007; Flowers et al., 2010). It has one of the most balanced nutritional compositions, and its protein quality is better than of other legumes such as pigeon pea, black gram and green gram (Singh et al., 2005a). The seeds contain 20-30% protein, approximately 40% carbohydrates and many other useful nutrients. Chickpea is also a good source of absorbable Ca, P, Mg, Fe and K (Christodoulou et al., 2005).
Due to their good amino-acid balance, high protein bioavailability, and relatively low levels of anti-nutritional factors, *C. arietinum*-seed form a suitable source of dietary proteins (Abou-Arab et al., 2010). Also, *C. arietinum* is a significant contributor to agricultural sustainability through biological nitrogen fixation (Zia-Ul-Haq et al., 2012) and as a rotation crop, allowing the diversification of agricultural production systems (FAO, 2004).

Two main types of *C. arietinum* cultivars (cvs.), representing two diverse gene pools, are distinguished by seed size, shape and colour. One produces relatively small seeds with an angular shape, dark colour and is called desi; the other produces large, rounded, cream colour seeds and is called kabuli (Naghai and Jahansouz, 2005; Iqbal et al., 2006). *C. arietinum* cv. Kabuli seeds are grown in temperate regions, whereas those of cv. desi type is grown in the semi-arid tropics (Naghai and Jahansouz, 2005; Iqbal et al., 2006). *C. arietinum* is a cold season crop grown under rainfed conditions with stored soil moisture in the sub-tropical environments like in India. Over 95% of the area, production and consumption of *C. arietinum* belong to the developing countries largely in South Asia and the Mediterranean region, with India being the largest producer contributing about 68% of the total global production, followed by Turkey, Pakistan and Mexico (FAO STAT, 2011). Since the plant is well adapted to environmental stresses such as drought, high temperatures and poor soils (Siddique et al., 1999), it may be an important food security crop for smallholder resource-poor farmers in the semi-arid tropics, and serve as an important winter rotational crop for commercial cereal farmers in this region. In spite of its good nutritional profile, the global *C. arietinum* production has more or less remained constant since 1960s (Rees et al., 2000).

In Indian context, according to the 2008 to 2009 estimates, its production was 7.06 million tonnes from about 7.89 million ha area, as compared with the World's *C. arietinum*-production of 9.23 million tonnes (FAOSTAT, 2009). During 2010-11, its production reached a record 8.25 million tonnes. Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Gujarat, Andhra Pradesh and Karnataka are the major chickpea-producing states, sharing over 95% area. During the period 1991-93 to 2008-10, highest increase in productivity was recorded in Andhra Pradesh (124%), followed by Karnataka (63%), Maharashtra (52%) and Gujarat (40%). Even though chickpea production increased significantly during the last decade, continuing fast
growth (in chickpea production) is a bigger challenge for researchers, extension agencies and policy makers. The current global yield average of *C. arietinum* is 0.9 t/ha, much lower than its estimated potential of 6 t/ha under optimum growing conditions (FAO, 2009). India is the largest producer of *C. arietinum*, but still is the largest importer. The chickpea yield in India has remained at 0.89 t/ha, which is much lower than the maximum yield reported in China i.e. 3.2 t/ha (FAO, 2009).

Chickpea productivity has been constrained by several abiotic stresses (Singh et al., 1994; Gaur et al., 2007); this accounts for 40-50% reduction in yield globally (Singh, 1985). Most of the cultivated areas have started showing signs of stress with production fatigue and deterioration of soil health. In many such areas, yields have started declining because of deceleration in total factor productivity, decline in organic matter content in soil and emergence of multi-nutrient deficiencies.

Zinc (Zn) is essential for normal plant growth and development, as carbohydrates, protein metabolism and sexual fertilization depend on Zn (Cakmak et al., 1989; Hall, 2002; Imtiaz et al., 2003; Vasconcelos et al., 2011). However, Zn-deficiency in crop production is spread worldwide (Alloway 2008a), and about half of the world's soils are deficient in Zn (Graham, 2008), mainly because of altered pH, salinity, high calcium-carbonate contents, high phosphate status and prolonged water logging (Alloway, 2009). In Indian context, about 50% of the pulse-growing districts of India are having Zn-deficiency (Ganeshmurthy et al., 2006). Zn-deficiency is a common yield-limiting factor in *C. arietinum*-production areas, including India (Ahlawat et al. 2007; Singh, 2008), which is vulnerable with about 50% Zn-deficient soils (Tandon, 1993; Alloway, 2009). Plants grown on such soils are unable to take up and translocate enough Zn to their edible parts. Zn-deficiency in crops thus reduces not only their yield, but also the nutritional quality of grain (Hossain et al., 2007). Additionally, more than half of the world's population suffers micronutrient undernourishment. Micronutrient malnutrition, and particularly deficiency in Zn, afflicts over three billion people worldwide, mainly due to deficiency of Zn in soils and crop produce. At present the demand for *C. arietinum* exceeds its production, especially in the South- and West-Asian countries and some North-African countries (Lovett and Gent, 2000; Kumar and Abbo, 2001). Increased industrialization has decreased opportunities for increase in agricultural areas. The situation of soil-Zn-deficiency is aggravating the status of micronutrient undernourishment globally.
Hence to keep pace with the unprecedented increase in *C. arietinum*-demand; its production needs to be increased by identifying *C. arietinum*-genotypes with high yield potential under rapidly increasing Zn-deficiency.

Although Zn-deficiency can be alleviated via fertilization, yet the agronomic (subsoil constraints, disease interactions), economic reasons (unavailability of Zn-fertilizers for poor farmers) and environmental factors (pollution due to excessive fertilizer use) restrain its excessive use in combating the problem (Graham and Rengel, 1993; Hacisalihoglu, 2002). So, alternative measures have to be taken to combat the problem.

Plants differ in their need of Zn and have evolved various physiological mechanisms to be able to adapt to the surrounding environment and maintain intracellular-Zn at an optimal level. Genotypes exhibiting significant genetic-based variation in their tolerance to Zn-deficiency and genotypic variations in Zn-uptake and utilization in Zn-deficient soils have been reported (Graham and Rengel, 1993; Fageria et al., 2002). Hence, Zn-requirement of crops can be easily met by identifying genotypes that are efficient in mobilization, uptake, utilization and translocation of Zn so as to sustain grain productivity on soils low in available Zn (Singh et al., 2005b). This could greatly enhance the efficiency of applied fertilizers, thus reducing the cost of inputs, decreasing the rate of nutrient losses, and enhancing crop yields. Therefore, cultivating Zn-efficient genotypes on Zn-deficient soil is an effective and sustainable approach for “tailoring the plant to fit the soil”.

The *C. arietinum*-genotypes differ in their sensitivity to Zn-deficiency (Khan, 1998; Khan et al., 1998). To this end, an efficient and sustainable solution to their Zn-deficiency is to develop and grow Zn-efficient genotypes, which may cope with low Zn-availability and grow and yield well under Zn-deficiency (Graham and Rengel, 1993). Thus, identification and cultivation of Zn-efficient *C. arietinum*-genotypes may help a lot in meeting the global demand for food and nutrition for the ever-growing human population. Genotypic differences in Zn-efficiency have been related to various mechanisms operating in the rhizosphere and within the plant system. Several traits associated with Zn-efficient crop plants have been identified, including processes that increase bioavailability of soil Zn and enhance Zn-uptake and its translocation from roots to the shoot (Khan et al., 1998; Grewal et al., 1997a).
Efficiency of a plant to absorb nutrients from sub-optimal growth condition is crucial in its overall performance with reference to yield and quality. However, for being Zn-efficient, a genotype should be able not only to absorb more Zn from deficient soils, but also to produce more dry matter and grain yield. Plants efficient in Zn-absorption and utilization were earlier reported to yield better under low soil-Zn conditions (Blair, 1993; Graham and Rengel, 1993). Although today we know that nutrient-efficient plants give higher yields per unit of nutrients applied or absorbed than normal (standards) plants under similar agro-ecological conditions (Fageria et al., 2008a), traits that can be used as potential indicators for Zn-efficient genotypes are poorly understood. The difficulty in identifying the potential traits has receded the progress and success of breeding programs for developing the nutrient-efficient crop genotypes. Thus, before selecting novel genotypes, secondary traits associated with Zn-efficiency should be identified for use in selection process along with final grain yield to increase the precision of selection. These traits can be used as potential indicators for efficient genotypes.

It is worthy to mention here that the difference in key traits of genotypes is the outcome of differences in physiological or molecular mechanisms governing them. Several nutrients are essential constituents of these mechanisms, as they are important components of various enzymes that are responsible for driving many metabolic reactions in plants, and deficiency of these important components leads to malfunctioning of these enzymes. Approximately 300 enzymes have been described that require Zn for their activity (Vallee and Falchuk, 1993), and Zn-dependent enzymes are found in all major enzyme classes (Broadley et al., 2007). One such enzyme is copper-zinc super oxide dismutase (Cu/Zinc SOD), which plays an important role in protecting plants against oxidative damage catalyzed by reactive oxygen species (Marschner and Cackmak, 1989). Zn is also directly involved in both gene expression and protein synthesis. Cakmak (2000) has speculated that Zn-deficiency may inhibit the activities of a number of antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids, proteins, chlorophyll and nucleic acids. Another well-characterized Zn-requiring enzyme is carbonic anhydrase (CA), the activity of which is being used as an indicator for diagnosing Zn-deficiency in plants (Bar-Akiva and Lavon, 1969). Zn-deficiency decreases the activity of CA, especially in Zn-inefficient genotypes (Rengel, 1995a). Therefore, more extensive
study is needed to identify more such indicators for nutrient deficiency in plants. *C. arietinum* is also a source of the bio-available Zn for human consumption. However, Zn-deficiency in soil has decreased its accumulation and distribution in various plant parts; plant genotypes respond differently to these mechanisms. Therefore, understanding the physiological effects and functions of Zn in plant systems, including the mechanisms involved in accumulation of zinc in edible portions of food crops is needed to find effective ways to increase its bioavailability. In plants, uptake and utilization efficiency of nutrients are governed by different physiological mechanisms. Thus, understanding the regulation of Zn-uptake, distribution, transport and the role of Zn in metabolism will be crucial in identifying the novel genotypes with enhanced yield and Zn-accumulation in edible plant parts.

Given the above, it was hypothesized for the current study that ‘identifying *C. arietinum*-genotypes with high Zn-accumulation and utilization potential and deciphering the underlying potential physiological determinants may help achieve clues vital for *C. arietinum*-breeding programs’.

The following objectives were set out to prove the above mentioned hypothesis:

**OBJECTIVES**

1. To screen the high and low zinc-accumulating genotypes of chickpea,

2. To understand the uptake and distribution pattern of Zn and other nutrients in the high and low Zn-accumulating genotypes,

3. To identify the factors regulating the accumulation and utilization of zinc in the selected genotypes, and

4. To examine the effect of zinc on nitrogen-utilization efficiency of the high and low Zn-accumulating genotypes.