India is one of the main wheat producing and consuming countries of the world. The series of agricultural changes that happened after 1965 in cereal production called Green Revolution made India self sufficient in wheat crop production. Wheat is one of the most durable and dependable cereal crops after rice, grown under diverse agro-climatic conditions, occupying nearly 31.3 million ha with a record production of 95.8 million tons during 2013-2014, and provides 20% of the total food calories of human requirement. Wheat has good nutrition profile with approximately 12.1 % protein, 1.8 % lipids, 1.8 % ash, 2.0 % reducing sugars, 6.7 % pentosans, 59.2 % starch, 70 % total carbohydrates; and provides 314 Kcal/100g of food. It is also a good source of minerals and vitamins viz., calcium (37mg/100g), iron (4.1mg/100g), thiamine (0.45mg/100g), riboflavin (0.13mg/100g) and nicotinic acid (5.4mg/100mg) (Lorenz and Kulp, 1991). Durum wheat (Triticum turgidum L. ssp. durum (Desf.) Husn.) belonging to tetraploid group, is the second most important wheat species, and widely grown in the semi-arid tropics of most parts of the world, including India. It is being cultivated in an approximate 10 to 11% of the world wheat area and accounting for about 8% of the total wheat production (Ganeva et al., 2011). Durum wheat serves as the raw material for numerous foods, such as, macaroni, semolina and pasta products in the nourishment of world population. Normally, durum wheat has higher feeding value in terms of quality traits compared to bread wheat (Beken et al., 1997). Grain protein concentration and composition along with bright yellow colour are the most important quality traits, which are to be given more emphasis in improvement of durum wheat. In general, durum carries high level of resistance to currently prevalent and bread wheat virulent leaf rust pathotypes and field tolerance to karnal bunt and loose smut, compared to bread wheat; and can protect the wheat crop against leaf rust epidemics in Central India, ensuring protection to the main crop of the Northern wheat belt by cutting down the inoculum supply along the “Puccinia-Path”. Thus, by promoting simultaneous cultivation of bread and durum wheat, higher genetic diversity can be maintained in wheat cultivation; and one species can complement for the weakness of the other, ensuring adequate protection against rust epidemics. Further, improvement in the production, productivity and nutritional value of durum wheat; and awareness about its consumption will provide a dependable source for higher economic returns to farmers and to raise the health standards of Indian population.

Drought is one of the most common environmental stresses that affect growth and development of plants. It is assumed that by the year 2025, around 1.8 billion people will face absolute water shortage and 65% of the world’s population will live under water-stressed environments. Drought, the result of low precipitation or high temperature, is thus
one of the main problems underlying the success of modern agriculture around the globe; and is one of the most important environmental factors that affect the growth, development and production of plants. Drought is a non-uniform phenomenon that influences plants differently depending on the development stage at the time of its occurrence (Arash et al., 2013).

Heat stress is another important environmental factor affecting the rate of plant growth and development (Marcum, 1998; Hall, 2001; Howarth, 2005; Sikder 2009). High temperature stress at the start and end of growing season usually constrain crop yield potential as these stresses coincide with the germination and grain filling period, respectively (Simane et al., 1993; Sarkar et al., 2001; Garcia del Moral et al., 2003; Koc et al., 2008). The problem of heat stress is likely to become even worse in the future under global environmental change, which has become one of the greatest challenges that humanity is facing today. The latest ‘Assessment Report’ of the Inter-Governmental Panel on Climate Change projects stated that the drought occurrence will increase especially for arid and semi-arid regions; and the global average temperatures in 2100 will be 1.8 to 4.0°C higher than the 1980-2000 average (IPCC 2007). However, eventhough water is not a limiting factor (e.g., supplied by irrigation), lower yields were obtained in dry and semi-dry environments as a result of heat stress that occurs during anthesis and grain filling periods (Savin et al., 1997 and Garcia del Moral et al., 2003), which imposes negative effects on production of wheat and other crops. These stress factors have negative influence on the movement of photosynthetic products to the developing grains and inhibits starch synthesis; thereby, it causes lower grain weight, which mightresult in lower grain yields (Bhullar and Jenner, 1985).

For healthy wheat growth and a good yield, the range of the optimum temperatures is 18 to 24°C. Temperatures above 28 to 32°C for short periods (e.g., 5 to 6 days) were found to cause about 20% or more wheat yield losses (Stone and Nicolas, 1994). Acevedo et al. (1991) had reported that every 1°C increase over 17 to 24°C in average temperature during wheat grain filling affects grain weight, and causes four percent yield reduction. Under these stress factors, the wheat crop completes its life cycle much faster than under normal conditions (Fischer, 1985); consequently, crop growth stages will have a short duration, with fewer days to accumulate assimilates during life cycle, and hence the production of biomass is reduced (Fischer and Maurer, 1976; Wahid et al., 2007).
Plants have a definite temperature requirement before they attain certain phenological stages. The accumulative heat units and system was adopted for determining the dates to flowering/heading and maturity of different field crops (Bierhuizen, 1973; Rajput et al., 1987; Bishnoi et al., 1995; Al-Karaki, 1999; Sikder, 2009). However, different phenological stages differ in their sensitivity to drought and high temperature stress, and this depends on plant species and genotypes, as there are great inter and intra-specific variations (Wollenweber et al., 2003; Howarth, 2005). It is high time to develop high yielding wheat varieties that are suitable to different stressful conditions. Future, increase in the potential yield of wheat will require an increase in the photosynthetic area in early growth stages, in order to augment the incident radiation intercepted by the crop and the total biomass produced (Slafer and Whitewchurch, 2001). Moreover, crop cultivars can fill their seeds/grains quickly and may have an advantage in environments with prevailing heat stress during seed/grain filling periods (Whan et al., 1996; Al-Karaki, 1999; Tewolde et al., 2006; Bavei et al., 2011), therefore, they can avoid the premature stoppage of grain growth and the acceleration of physiological maturity in early maturing cultivars under stress environmental conditions such as high temperature.

Mostly, bread wheat is mostly grown under early sown conditions, whereas, durum wheat varieties yielding of medium-late maturity suitable for growing under these conditions with matching yield potential are not available. Hence, there is substantial scope for identification of suitable durum wheat genotypes for early sown conditions; and their improvement in production and productivity under unfavorable environments that are characterized by high temperature and drought conditions. Analysis of variability among the traits and the association of a particular character with other traits contributing to grain yield of a crop would be of great importance in planning a successful breeding programme. Heritability, the degree to which the variability of a character is transmitted to the progeny, serves as a guide to the reliability of phenotypic variability in the selection programme, and hence determines its success. However, heritability estimates together with genetic advance are more important than heritability alone to predict the resulting effect of selecting the best individuals. High genetic advance coupled with high heritability estimates offers the most effective condition for selection. Path-coefficient analysis provides means to quantify the inter-relationship of different yield components and indicate whether the influence is directly reflected in the yield or take some other pathways to produce an effect.
Selection based on high yield *per se* is empirical due to low heritability and a high genotype-environment interaction (Reynolds *et al.*, 1999). It also requires the evaluation of a large number of advanced lines in field yield trials over years and locations (Ball and Konzak, 1993). An indirect selection method that gives an early yield prediction is a potential alternative approach for screening large numbers of genotypes in breeding programmes for identifying and selecting high-yielding lines (Shorter *et al.*, 1991; Marti *et al.*, 2007). However, the development of a selection index must integrate several traits, their interrelations and repeatability (high heritability) for predicting yield in breeding programmes (Baker, 1991; Bouman, 1995).

The phenotypic performance of a genotype is not necessarily the same under diverse agro-ecological conditions (Ali *et al.*, 2003). Genotype-environment (GE) interactions are extremely important in the development and evaluation of plant varieties because they reduce the genotypic stability values under diverse environments (Hebert *et al.*, 1995). The concept of stability had been defined in several ways and several biometrical methods including univariate and multivariate ones are in use (Crossa, 1990). A good method for measuring stability was previously proposed (Finlay and Wilkinson, 1963) and was later improved (Eberhart and Russell, 1966). The stable variety was defined by a high mean yield, regression coefficient \( b_i = 1.0 \) and the deviations from regression as small as possible \( S^2d_i = 0 \). In addition, the stability was defined as adaptation of varieties to unpredictable and transient environmental conditions and the technique has been used to select stable genotypes unaffected by environmental changes (Allard and Bradshaw, 1964). The levels of heterosis, general and specific combining abilities of parental lines were sufficient to sustainable production of hybrid breeding and early selection of breeding lines (Akinci, 2009).

As per the mandate of IARI, Regional Station, Indore, major thrust has been on the improvement of productivity of durum and bread wheat in Central India, through development of high yielding, rust resistant and quality wheat varieties. IARI released durum wheat varieties during the past two decades are Malavshree (HI 8381), Malav Shakti (HI 8498), Malav Ratna (HD 4672), Malav Kirti (HI 8627), Poshan (HI 8663) and Pusa Mangal (HI 8713). With intensive popularization of these newly evolved varieties under different cultivation conditions and their “low cost cultivation technology”, wheat productivity in Madhya Pradesh has improved from 18 q/ha to 25 q/ha. The popularization of durum wheat in the form of recommending the cultivation of varieties like HI 8381
The main characteristics of released durum wheat varieties from IARI – Indore are:

**HI 8381 (Malavshree):** Double dwarf and medium late variety for timely sown high fertility conditions of Central India. Ears are pubescence with black awns. The grains are very bold, amber colour with good β-carotene and protein content.

**HI 8498 (Malavshakti):** Double dwarf and medium early variety for timely sown high fertility conditions of Central India. It has glabrous and white ears with uniform, very bold grains and high protein and high β-carotene content (Fig 1.2).

**HD 4672 (Malav Ratna):** A semi-dwarf, medium late maturity variety for rainfed and limited irrigation conditions of Central India. It has glabrous ears, white in colour and black awned. Grains are very bold with good quality traits. Its extraordinarily high levels of resistance to stem and leaf rusts can prevent the early build up of rusts on October/early November sown wheat crop in Central India.

**HI 8627 (Malav Kirti):** A semi-dwarf, medium late maturity variety for rainfed and limited irrigation conditions of Central India. High yields of HI 8627 under all sowing conditions from October to November end proved its thermo-tolerance which can help in sustaining wheat production under challenges of “Global Warming”. Besides its “dual quality” (suitable for chapati as well as macaroni preparations add rich combinations of protein, β-carotene, iron, zinc and copper, it can ensure “Nutritional security” at household level, providing “Health Food” to rural India.

**HI 8663 (Poshan):** A novel genotype characterized by excellent grain quality with high and stable yield, it is a double dwarf and medium late variety for timely sown high fertility conditions of Peninsular India. It can serve as a “naturally bio-fortified health food” and can be used for “dual purpose”, i.e., both for “nutritive chapati” and for fast food preparations. It has glabrous and white ears with uniform medium bold grains. It contains high and stable β-carotene, high sedimentation value, high protein content and high levels of micronutrients, particularly iron and zinc.

**HI 8713 (Pusa Mangal):** A high yielding and stable genotype recently released characterized by excellent grain quality. It is a semi-dwarf and medium late variety for timely sown high fertility conditions of Central India. It can be used for fast food preparations. It has glabrous and white ears with uniform medium bold grains. It contains
high β-carotene (~7.1 ppm), medium sedimentation value, high protein content and high levels of micronutrients, particularly iron and zinc.

Fig. 1.1: India wheat production and major durum wheat growing areas

HI 8627 (Malav Kirti)  
HI 8498 (Malavshakti)  
HI 8663 (Poshan)

HD 4672(Malav Ratna)

Fig.1.2: Released durum wheat varieties
Targeted wheat varieties with high stable grain yield and tolerance to heat and drought can restore wheat productivity in areas vulnerable to climate change induced stress, thereby reducing threat to over 900 million people, one seventh of the world population. Breeding for early heat and drought tolerant durum wheat genotypes has become an integral part of the crop improvement activities at the national and international level, which helps not only in increasing area under durum wheat cultivation in non-traditional areas, but will also optimize the durum wheat yield in traditional cultivation under multiple cropping systems. Genotypes that showed better and stable performance for yield in highly stressed environments at one location may perform better at similar locations elsewhere (Reynolds et al., 2007). High-yielding genotypes do not perform on par with abiotic stress-adapted genotypes, when yield is depressed below a crossover point. Although, approaches other than that based on breeding for yield per se have been proposed (Reynolds et al., 1998), yield and yield traits continue to be important in measuring the success of a genotype in heat-stressed environments. A genotype with stable and high yield across the environments would be more suitable as a cultivar and as a donor parent for further breeding in hot environments that vary over the years and within a particular year across locations.

Slowly, durum wheat is gaining popularity among Indian farmers as recently released semi dwarf high yielding cultivars are more resistant to Karnal bunt and leaf rust than bread wheat. Therefore, attempts are to be made to select high yielding durum genotypes for early sown conditions with high heat tolerance under moisture stress to combat the climate change effects and global warming. However, detailed systematic information about the performance of durum wheat genotypes under rainfed and restricted irrigation conditions is not available. Keeping this in view, the present study “Studies on physiological and biochemical changes in relation to grain yield, quality and drought tolerance in durum wheat genotypes” was planned to identify durum wheat genotypes suitable for growing under early sown and moisture stress condition with the following objectives:

- To study the physiological and biochemical changes in durum wheat genotypes for high grain yield, good grain quality and drought tolerance.
- To determine the nature and magnitude of associations between yield, quality and related morphological traits to develop a selection index.
- To identify the better cross combinations having high photosynthetic efficiency.