Studies on carbohydrate metabolism in wheat under drought and high temperature conditions

By

KIRPA RAM

2013BS10D

Thesis submitted to the Chaudhary Charan Singh Haryana Agricultural University in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN PLANT PHYSIOLOGY

Department of Botany and Plant Physiology
College of Basic Sciences and Humanities
CCS Haryana Agricultural University
Hisar - 125004 (Haryana)

2017

CERTIFICATE – I

This is to certify that this thesis entitled, **"Studies on carbohydrate metabolism in wheat under drought and high temperature conditions"**, submitted for the degree of **Doctor of Philosophy** in the subject of **Plant Physiology** of the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mr. Kirpa Ram** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

Dr. (Mrs.) Renu Munjal
(Major Advisor)
Principal Scientist and Head
Department of Botany and Plant Physiology
College of Basic Sciences and Humanities
CCS Haryana Agricultural University
Hisar – 125004, (Haryana) INDIA

CERTIFICATE – II

This is to certify that this thesis entitled, **"Studies on carbohydrate metabolism in wheat under drought and high temperature conditions",** submitted by **Mr. Kirpa Ram** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in the subject of **Plant Physiology** has been approved by the Student's Advisory Committee after an oral examination on the same.

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Acknowledgement

"Be-don't try to become"

-Osho

I express my heartiest devotion to the almighty God for his graceful blessing at every step without which nothing could have been accomplished.

With immense pleasure and deep sense of gratitude, I express my sincere thanks to my major advisor, ***Dr. (Mrs.) Renu Munjal****, Principal Scientist and Head, Department of Botany and Plant Physiology, CCS HAU, Hisar for her appreciated scientific supervision, constant inspiration, generous help and close supervision throughout the tenure of this study. Her unabridged hearted keen interest, technical shrewdness, parental and sympathic insolence during the entire period of my study for Ph.D. programme will always remain alive in my mind.*

I am sincerely obliged and grateful to members of my advisory committee Dr. K.D. Sharma (Principal Scientist), Dr. S.S. Dhanda (Principal Scientist), Dr. V.K. Phogat (Principal Scientist) and Dr. H.R. Singal (Principal Scientist) for their keen interest, valuable comments and guidance offered during course of this investigation.

I am highly thankful to Dr. Ram Niwas, Computer Section, College of Basic Sciences & Humanities for statistical analysis of the data.

I am highly thankful to my friends Dr. Rajkumar, Pooja Swami, Sunita and my seniors Dr. Naveen Kumar, Dr. S.S. Arya and Dr. Divya Phogat for all around help received during my study.

No word of mine can adequately express my indebtedness of my father Sh. Suraj Bhan, mother Smt. Vidya Devi and my uncle Mahabir Singh without whose blessing, love, infinite help and moral inspiration this investigation would not have been completed.

Stipend awarded by CCS Haryana Agricultural University, Hisar is fully acknowledged.

(Kirpa Ram)

Date 02/01/2018

Place: Hisar

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LIST OF ABBREVIATION USED

Abbreviation	Full form
Control	Irrigated
D40	Drought at 40 days after sowing
D65	Drought at 65 days after sowing
D40+D65	Drought at 40 and 65 days after sowing
DR	Complete drought
RBD	Randomized block design
OP	Osmotic potential
WP	Water potential
RWC	Relative water content
WSC	Water soluble carbohydrate
SuSy	Sucrose synthase
INV	Invertase
SBE	Starch branching enzyme
SDBE	Starch debranching enzyme
AGPase	ADP-glucose pyrophosphorylase
GGR	Grain growth rate
GFD	Grain filling duration
SI	Susceptibility index
cm	Centimeter
kg	Kilogram
g	Grams
et. al.	et alia (and others)
Fig.	Figure
SPAD	Soil plant analysis development
%	Per cent
µM	Micro molar

CHAPTER-I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop for the majority of population and staple food of about two billion people (36% of the world population). Wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally (Breiman & Graur, 1995). Wheat domestication in India started 5000 years ago (Feldman, 2001). India holds the position of being the second largest wheat producing country for many years and contributes about 36 per cent to the country's total food grains production (Anonymous, 2015). Currently, wheat covers 220 mha area and produces 724 million tones in 2016-17, worldwide (FAO, 2017). The current year (2016-17) wheat production has reached an all-time record of 97.44 million tonnes (mt) with an average national productivity of 3172 kg/h (Anonymous, 2017). Abiotic stresses are important constraint limiting the crop productivity worldwide. Plants show a wide range of responses to drought and heat stresses which are mostly depicted by a variety of alterations in the growth and morphology of plants. Although drought and heat stress may cause negative effects on overall growth and development of the plants, the major phase being damaged is the reproductive growth. Heat and drought are undoubtedly the two most important stresses having huge impact on growth and productivity of the crops. It is very important to understand the physiological, biochemical, and ecological interventions related to these stresses for better management (Fahad *et al*. 2017).

High temperature stress (HS) at any developmental stage can diminish not only growth but also grain yield of wheat crop. Yield reduction is associated with both chronically high temperature as well as heat shocks, where temperature rise more than 32°C during mid or late reproductive stages, including grain filling stage in wheat (Wardlaw & Wrigley, 1994; Ihsan *et al.* 2016). There are two main pathways which ultimately affect the yield. First, high temperature causes faster crop development and thus shorter crop duration, which results in lower yields (Stone, 2001). Second, high temperature influences the photosynthetic rate, respiration and grain filling. Increase on temperature during the day can increase or decrease photosynthetic rate, depending on the current temperature respective to optimum (18-24 ^{o}C), whereas increase in night temperature raises respiration costs without any potential benefit for photosynthesis. 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 challenge that the humanity faces today. High temperature represents a major constraint affecting wheat, particularly at the reproductive stage, in many parts of the world (Asseng *et al.* 2011). High temperature reduces yield by 3-4% per °C rise in temperature (Tack *et al.* 2015; Troy *et al.* 2015; Mueller *et al.* 2016).

Heat stress affects almost every growth stage of wheat. The optimum temperature for growth and yield of wheat is in the range 18–24ºC, temperature above (25-32ºC) for longer duration (1-2 weeks) and very high temperature (33-40ºC) for short period (1-2 days) causes gradual heat stress and heat shock, result in significant decreases in yield of 20% or more (Larkindale *et al.* 2005). Efficient photosynthesis and assimilate partitioning during the vegetative phase has a decisive role in the formation of generative organs and thus directly affects the final yield (Wardlaw, 1990; Wang *et al.* 2015; Brestic *et al.* 2016). Heat stress during reproductive phase is particularly detrimental, resulting in reduction of both individual kernel weight and kernel number due to the sensitivity of microspore and megaspore development and shortens duration of grain filling and decrease time to apoptosis and maturity (Ahmed & Hasan, 2011). These effects restrict the growth, biomass production and productivity along with quality of produce (Lobell & Asner, 2003; Peng *et al.* 2003; Lohraseb *et al.* 2017). It has been reported that each degree celsius rise in temperature beyond cardinal causes reduction by 5-8% in grain filling and 5% in gain weight leading to 3-4% reduction in total grain yield (Bagga & Rawson, 1977; Tashiro & Wardlaw, 1989).

In the Indo-Gangetic plains of South Asia about 20 percent of total area under wheat is sown after middle of December (Sharma *et al.* 2014) warranting alternate production strategies. Heat stress is thus, one of the major abiotic stresses that impacts global wheat production especially in area associated with higher temperature during crop seasons. Reduction in yield is associated with both chronically high temperature during early grain filling as well as during late reproductive stage including grain filling. Terminal heat stress is a problem of 40% temperate wheat environment (Hays *et al.* 2007; Reynolds *et al.* 2016)

Water stress is of common and wide occurrence in nature. It occurs when absorption of water is lower than the evapotranspiration. There are two major processes involved in drought condition. First, absorption of water by the crop controlled by root architectures and soil properties. Second, evapotranspiration (ET) of crops depends on temperature, vapour pressure deficit (VPD) and crop canopy characteristics. Drought is an another major environmental stress threatening wheat productivity worldwide. Global climate models predict changed precipitation patterns with frequent episodes of drought. Although drought impedes wheat performance at all growth stages, it is more critical during the flowering and grain-filling phases (terminal drought) and results in substantial yield losses (Pradhan *et al.* 2012). The severity and duration of the drought determine the degree of the yield loss. The effects of terminal drought on wheat yields are likely to increase in the near future (Oliveira *et al.* 2015). Grain filling and grain yield are dependent on systematic utilization of water soluble reserved carbohydrates in flag leaf sheaths and stems under stress condition (Wardlaw and Willenbrink, 2000).

Water deficit conditions resulted in early senescence and faster remobilization of pre-anthesis reserved assimilates to developing grains in cereal crops (Saeedipour & Moradi, 2011). Glucose, fructose, sucrose and starch are storage sugar in leaf, stem and developing grain and fructan is main reserved carbohydrate (Scofield *et al.* 2009). Drought induced earlier mobilization of non-structural reserve carbohydrates (largely, fructans) from stem and leaf sheaths, which provided a greater proportion of kernel dry weight at maturity (Chen *et al.* 2015). It can account for 70-92 per cent of grain dry matter, under conditions of drought (Gupta *et al.* 2011; Zhang *et al.* 2015). It is generally accepted that stem reserve mobilization or percentage of stem reserves in grains is posh by sink size, environment and cultivar (Blum, 1998; Ferrise *et al.* 2015). It has been suggested that wheat genotypes synthesize and store maximum concentration of water soluble carbohydrates in the stems before anthesis and improve grain yield under water deficit condition (Yang *et al.* 2007; Gupta *et al.* 2011).

Sink-source dynamics within a plants by which grasses produce, transport, and store carbohydrates underpins all aspects of yield traits. Manipulating stem non-structural carbohydrates (NSCs) provides one avenue to stabilize and increase productivity in the face of rapidly changing demand in the next century (Slewinski, 2012). High soluble sugar concentrations in the stems may also be an adaptive trait in grasses that have low optimal hydraulic conductance, in order to pull water from the soil into the vegetative parts of the plants, such as the mechanisms proposed in trees (Fu *et al.* 2011). Stem water-soluble carbohydrates (WSC) can be an important contributor to buffer grain yields against unfavorable conditions for photosynthesis during grain-filling period (Li *et al.* 2015). Mobilization of WSC during grain filling can potentially contribute about 20% of the final grain weight under non-stress conditions, and up to 70% or more of grain dry matter under drought stress in wheat (Goggin & Setter, 2004). Stem water-soluble carbohydrates are a major carbon source for grain filling under drought and high temperature stress (Zhang *et al.* 2016). The amount of WSC accumulation and remobilization reportedly differs between internodes (Ehdaie *et al.* 2006). Phloem translocation remained unaffected until late in the stress period, when other processes, such as photosynthesis, had already been strongly inhibited (Taiz & Zeiger, 2010). Relative insensitivity of translocation to stress, plant reserves can be mobilized to grain. The continuing translocation of assimilates could be a key ability for drought and heat tolerance. Under drought stress, stem water soluble carbohydrate (WSC), mainly fructans, represents a long-term carbon storage form functioning as a major carbon source for grain filling (Pollock and Cairns, 1991; Verspreet *et al.* 2015). The high remobilization efficiency of stem WSC could contribute to high water use efficiency (Passioura, 2012; Zhang *et al.* 2015a). Fructans may also be involved in osmoregulation under drought and high temperature (Schnyder, 1993; Turner *et al.* 2008; Gélinas *et al.* 2016). Stem fructans may also contribute to recovery mechanisms under biotic and abiotic stresses (Valluru & Van den Ende, 2008; Livingston *et al.* 2009). Furthermore,

sucrose, hexoses (Hex) and small fructans may act as phloem-mobile signaling molecules under stress, contributing to stress tolerance and disease prevention (Van den Ende, 2013; Ruan, 2014).

WSC are non-structural carbohydrates that include fructose, glucose, sucrose and fructans, with fructans as the major component (Zhang *et al.* 2015). WSC are accumulated during vegetative growth up to just after anthesis and are remobilised to the growing grains during grain filling (Ehdaie *et al.* 2008; Ruuska *et al.* 2006). Remobilization of WSC to grains increases with post-anthesis water stress, when photosynthesis declines (Ruuska *et al.* 2006; Yang *et al.* 2003). Genetic diversity of wheat stem water soluble carbohydrates ranges from 10% to 50% of total stem dry weight (Rebetzke *et al.* 2008; Cossani & Reynold, 2012) and strongly associated with gene of carbohydrate metabolism at transcript level (Xue *et al.* 2008). Integration of physiological traits, genetic and genomic tools, and transgenic approaches may also help to improve resistance against drought in wheat. (Farooq *et al.* 2014; Biesiekierski & Iven, 2015; Cimini *et al.* 2015).

A comprehensive understanding of the impact of terminal drought is critical for improving drought resistance in wheat. Drought and high temperature at grain filling impair current photosynthesis and reduce crop productivity. Carbohydrates serve as reserves to support grain filling under stress. Adaptability to theses stress environments can be facilitated by resilient wheat cultivars with inbuilt mechanism. Keeping in view the above facts, the present work was planned on eight wheat genotypes with the following objectives:

1. To assess the effects of drought and heat stress conditions on carbohydrate accumulation and partitioning.
2. To identify physiological and biochemical traits related to accumulation and partitioning of carbohydrate under drought and heat stress conditions.

CHAPTER-II

REVIEW OF LITERATURE

Wheat is a vascular (*Tracheobionta*), flowering (*Magnoliophyta*), and monocotyledon (*Liliopsida*) plant (*Plantae*) belonging to the fifth largest plants grasses family (*Poaceae*). *Triticeae* is one of the tribes containing more than 15 genera and 300 species including wheat and barley (Barnhart, 1895). Wheat is first classified by Linnaeus in 1753. In 1918, Sakamura reported the chromosome number sets (genomes) for each commonly identified wheat genotype and separated into three groups *viz.* diploids (2n=14), tetraploids (2n=28) and hexaploids (2n=42) chromosomes. There are many taxonomic classifications which diverge on some controversial points such as the genus classification; considering one unique *Triticum* genus, or two different genera: *Triticum* and *Aegilops* (NGRL, 2004). It is cultivated over a wide range of climatic conditions and therefore understanding of physiological and biochemical value for genetics and plant breeding purposes.

Carbon metabolism in plants is one of the key physiological processes determining crop growth, yield and quality; and is very sensitive to abiotic stresses. In cereals like wheat, carbohydrates supporting grain growth during the grain filling stage are derived from two sources, namely the current photo-assimilate and stored carbohydrate reserves in vegetative organs which can be remobilized into the grains (Gebbing *et al.* 1999). Combination of drought and high temperature strongly affects the grain-filling processes in wheat directly by damaging photosynthetic apparatus or by reducing photosynthate accumulation during grain growth.

Wheat is the world's most widely grown food crop which provides one fifth of the global calorie consumption (Reynolds *et al.* 2011). Environmental constraints are major factors in productivity of wheat in many regions of the world (Kronstad, 1996). Both drought and high temperature adversely affect photosynthesis in wheat. Drought rapidly reduces expansion of leaves and stomatal conductance and may eventually impact primary events in the photosynthetic process (Passioura, 1994). High temperatures are unlikely to reduce the accumulation of dry matter by limiting the supply of assimilate to the grain (Wardlaw *et al.* 1980) but drought impacts include growth, yield, membrane integrity, pigment content, osmotic adjustment water relations, and photosynthetic activity (Praba *et al.* 2009). Stress during the reproductive phase also induces abortion of kernels, probably by decreasing the supply of carbohydrates, and reduces the number of endosperm cells and amyloplasts in the grain (Saini & Westgate, 2000). When drought and high temperature occur simultaneously effects the plant water relations in wheat seedlings like relative water content, water potential, osmotic potential, and turgor potential (Machado & Paulsen, 2001). High temperature without drought stress had little effect on maturing plants, but combined effect of high temperature and drought decreased the number and size of endosperm cells and their content of starch granules, effects that were

greatly accentuated at 28 ^{0}C compared with 23 ^{0}C (Nicolas *et al.* 1984). The research work pertinent to the present study in India as well as abroad is reviewed under following headings:

2.1 Effect of drought and high temperature stress on phenological parameters

2.2 Effect of drought and high temperature stress on physiological parameters

2.3 Effect of drought and high temperature stress on biochemical parameters

2.4 Effect of drought and high temperature stress on yield parameters

2.1 Effect of drought and high temperature stress on phenological parameters

Climate change affect the phenology of cereal crop development from emergence through anthesis to physiological maturity is largely controlled by temperature, but also strongly affected by drought stress (Olesen *et al.* 2011). Phenology plays directly and indirectly controls by acting as a specific biological time balance on processes like senescence, grain filling, photosynthesis and nutrition uptake (Lopes *et al.* 2015). Drought and high temperature reduce growth period for various development stages *i.e.,* tillering, jointing, booting, heading, anthesis, grain filling and maturity (Hossain *et al.* 2013). These stress resulted in physiological and metabolic metabolism disturbance with shorter plant life cycle (Tuteja & Sarvajeet, 2012) and finally reduction in biomass accumulation and grain yield (Hasanuzzaman *et al.* 2013; Ihsan *et al.* 2016). Prasad *et al.* (2008) and Hossain and Teixeira da Silva (2012) reported a decrease in time to flowering, grain set, and physiological maturity in spring wheat when grown at high night temperature (>14 °C).

Wollenweber *et al.* (2003) and Howarth (2005) stated that the different phenological stages of different genotypes differ in their sensitivity to climatic factors, especially high temperature (air and soil) and drought depends on species and genotype due to inter- and intra-specific variations. Hossain and coworkers in 2013 observed reduction in life span of the late sown wheat due to the negative effect of high temperature (air and soil) and drought (deficit soil moisture). Ubaidullah *et al.* (2006) also noticed that heading, anthesis and grain maturity were 23 to 29 days earlier when wheat was sown late than when sown normally due to heat stress.

At anthesis, high temperature stress decreases the grain number by adversely affecting ovary development, pollen germination and pollen tube growth (Stone & Nicolas 1994; Yang *et al.* 2002; Prasad *et al.* 2008).

2.2 Effect of drought and high temperature stress on physiological parameters

2.2.1 Water relation traits

The water status of a crop plant is usually expressed in terms of water content, water potential and other water relation related components (Javed *et al.* 2011). Leaf water potential (WP), osmotic potential (OP) and relative water content are characteristics that can be selected to improve the high temperature and drought tolerance of different crops (Nayyar *et al.* 2005;

Huang *et al.* 2013; Munjal & Dhanda, 2016 & 2017; Mishra *et al.* 2017). Osmotic adjustment resulted in the active accumulation of solutes in cells as a response to a reduction in the water potential by maintaining turgor pressure which helps in soil water absorption and continue plant metabolic activities for its survival (Bilal *et al.* 2015). Lower osmotic potential lead to the resistance to drought condition implying that genotype has adapted to drought through effective osmoregulation (Hura *et al.* 2007). Ghobadi and coworkers in 2013 observed that exposure of plants to drought stress substantially decreased the leaf osmotic potential. Marcinska *et al.* (2013) found that osmotic stress affected water status, osmotic potential in drought-resistant and drought-susceptible wheat genotype. More negative leaf water potential and osmotic potential was recorded under water deficit conditions than the control at all growth stages (Raza *et al.* 2014). Marechaux *et al.* (2015) found that osmotic potential shows a decreasing trend with time under water deficit condition. The mean value for OP at terminal drought was found higher (-1.87 MPa) compared to (-1.40 MPa) control treatment (Chachar *et al.* 2016).

Drought reduced leaf water potential, unbalanced cell turgor and retard growth by accelerated leaf senescence (Vesala *et al.* 2017). The higher leaf water potential and relative water contents were associated with higher photosynthetic rate (Sharma *et al.* 2016). Water potential of leaves decreased significantly under water stress conditions. Soil water availability impacts growth, rooting traits, water relations and photosynthetic activity (Kumar & Sharma, 2010; Dhole & Reddy 2010). Iqubal *et al.* (2014) reported that drought stress reduces the water potential -0.63 in control to -2.00 in stressed conditions. Habash *et al.* (2014) reported a linear relation between relative water content and water potential in flag leaves of duram wheat. High temperature impose negative effects on leaf of plant and reduced water potential, leaf area and increase rate of leaf senescence which have negative impacts on photosynthesis and carbohydrate accumulation (Greer *et al.* 2012). Ram *et al.* in 2017 found combination of drought and high temperature are more dangers during grain filling stage and showed reduction in osmotic potential, water potential and relative water content in wheat genotype.

Relative water content (RWC) reflects the plant leaf water status in terms of the physiological significance of water deficit at cellular level and the balance between water supply to the leaf tissue and transpiration rate (Anjum *et al.* 2011; Huang *et al.* 2013). Water deficiency was found to reduce the relative leaf water content in wheat genotypes under drought stress condition as compare to controlled plants (Naeem *et al.* 2015). Tambussi *et al.* (2007) reported that under drought stress a significant decrease in RWC (85 and 55% after 6 and 8 day of withholding water, respectively). Munjal & Dhanda (2016) found a significant association of RWC with grain yield under drought stress conditions. Increase in temperature by delayed sowing significantly decreased relative water content (RWC) from 8 to 23 days after anthesis (DAA) (Sairam *et al.* 2000; Bhesaniya, 2005). The high temperature stress mediated effect on RWC displayed a progressive decrease in four wheat cultivars studied by Mishra *et al.* 2017.

Relative water content was higher in tolerant genotypes when compared to susceptible genotypes but as temperature increased, they were decreased in both the heat susceptible & tolerant genotypes at both tillering & grain filling stages (Ramani *et al.* 2017; Ram *et al.* 2017).

2.2.2 Chlorophyll related traits

Chlorophyll fluorescence analysis provides a sensitive indicator of stress conditions in plants. It can be used to estimate the activity of thermal energy dissipation in photosystem II, which protects photosynthesis from the adverse effects of light and heat stress (Almeselmani *et al.* 2011). Combination of drought and heat stress have more drastic effect on Fv/Fm than each stress alone (Wang *et al.* 2010; Almeselmani *et al.* 2012). Khakwani *et al.* (2012) reported that there is a significant effect of water stress on chlorophyll fluorescence. Lu & Zhang (2000) reported that significant decrease in the Fv/Fm ratio when plants were exposed to high temperatures (40-45.5^{0}C). Genotypes with greater value of Fv/Fm had also higher yield, indicating that chlorophyll fluorescence is an important criterion, could be utilized in the screening for heat-tolerant genotype (Efeoglu & Terzioglu, 2009).

Chlorophyll content is the other physiological trait which can be either rapidly phenotypic and/or informative about how adaptation to drought can arise (Abdipur *et al.* 2013). Drought stress causes not only a significant damage to photosynthetic pigments, but it also causes deterioration of thylakoid membranes (Huseynova *et al.* 2009, Anjum *et al.* 2011, Kannan & Kulandaivelu, 2011). Effects of drought stress on chlorophyll content and RWC wheat cultivar under field conditions showed a decrease in total chlorophyll and relative water content (Shamsi, 2010). Wang *et al.* (2010) studied the different responses of wheat plants to drought and heat stress and reported that heat stress & drought decreased the chlorophyll content. Rehman *et al.* (2016) found a reduction in total chlorophyll by 10% in wheat genotype under drought condition. Heat stress declined chlorophyll contents in cool-season cereal species which leads to physiological changes & thereby leaf senescence (Almeselmani *et al.* 2012). Chlorophyll content of heat sensitive genotypes was found highly reduced in late sown condition as opposed to timely sown (Khan *et al.* 2014; Ram *et al.* 2017a). High temperature reduced leaf chlorophyll content by 8.84 & 12.02 % at anthesis and 15 DAA, respectively, as compared to control plants (Gupta *et al.* 2015).

2.2.3 Stem reserve mobilization

Carbon requirements for grain filling in wheat are mainly from current assimilation by photosynthesis and remobilization of reserves from the stems (Yang *et al.* 2000). Remobilization of assimilates is an active process that involves translocation of stored reserves from stems and sheaths to grains (Gupta *et al.* 2015). Stem reserves contribute 20 to 40% weight of the grain in non-stressed condition (Vignjevic *et al.* 2015) and this can be up to 70% under stressed conditions during grain filling (Rebetzke *et al.* 2008). Drought and high temperature induced earlier mobilization of non-structural reserve carbohydrates from stem and leaf sheaths,

which provided a greater proportion of grain dry weight at maturity. It can account for 70-92 per cent of grain dry matter, under conditions of drought (Yang *et al.* 2002; Pradhan *et al.* 2012). Accumulation of WSC depends on the environmental conditions, and it starts from internode elongation and continue up to grain filling stage in wheat (Dreccer *et al.* 2009). Heat (Wang *et al.* 2012) or water stress (Ehdaie *et al.* 2008; Gupta *et al.* 2011) can reduce WSC reserves and its mobilization to the grain growth. But under heat stress, plants can only partially compensate for reduced stem WSC content by increasing mobilization efficiency (Wang *et al.* 2012). Mobilization of WSC from the upper part of stem (such as peduncle and penultimate internode) appears to start at 21 DAA when the grain is about one third of its final mass (Ehdaie *et al.* 2006, 2008). However, such mobilization is started earlier at 10 DAA from the lower part of stem through peduncle in wheat (Ehdaie *et al.* 2006, 2008). There is a strong positive correlation between stem dry matter and stem WSC content, which suggests that post-anthesis changes in stem dry weight in wheat could be an effective indirect method to estimate the amount of stem reserves accumulated and mobilized to grain (Ehdaie *et al.* 2008)

2.3 Effect of drought and high temperature stress on biochemical parameters

2.3.1 Metabolites

The stems of small grained species store carbohydrates in the form of glucose, fructose, sucrose and starch, but the main reserve is fructan (Dubois *et al.* 1990; Wardlaw & Willenbrink, 1994). Storage is commonly analysed as total nonstructural carbohydrates (TNC) or water-soluble carbohydrates (WSC) (Ruuska *et al.* 2006). WSC are accumulated during vegetative growth up to just after anthesis and are remobilised to the growing grains during grain filling (Ehdaie *et al.* 2008; Ruuska *et al.* 2006). Remobilisation of WSC to grains increases with post-anthesis water stress, when photosynthesis declines (Ruuska *et al.* 2006; Yang *et al.* 2003). Water soluble carbohydrate (sucrose and starch) is produced in plastids/cytoplasm from excess sugars during photosynthesis and involves ADP-glucose pyrophosphorylase (AGPase), starch synthases, branching enzymes, and debranching enzymes. Phosphorylation of starch granules by glucan-water dikinase (GWD) and phosphoglucan-water dikinase (PWD) stimulates starch degradation. β-amylases produce maltose from glucans. In the cytosol, maltose is converted to glucose and subsequently, fructose and sucrose are formed (Tetlow *et al.* 2004; Kotting *et al.* 2010).

The importance of WSC to grain yield increases when stress reduces the amount of current photo-assimilate produced and under severe stress WSC may become the predominant source of carbohydrates for the developing grain. If WSC storage was higher than the adverse effects of terminal drought (van Herwaarden *et al.* 1998) and heat (Wang *et al.* 2012) could be offset by increased remobilization. Under non-stress conditions, WSC can contribute 10–20% of total grain weight (Shearman *et al.* 2005) and this contribution can increase to 30-50% when conditions are unfavorable (Blum, 1998; Ehdaie *et al.* 2008). Therefore, high WSC

concentration is considered an important contributor to grain weight and yield under arrange of stress conditions, including heat stress (Blum,1998; Foulkes *et al.* 2007; Xue *et al.* 2009; Saint Pierre *et al.* 2010). WSC were determined in 13 barley cultivars and shown to be correlated (r=0.76) over two experimental sites (Kotting *et al.* 2010). Similarly, six wheat cultivars were grown at a single site over 3 years and their ranking for WSC content was generally maintained (Foulkes *et al.* 2002). Van Herwaarden *et al.* (2003) found that eighty wheat genotypes, in stress environment, identified large among-genotype differences in WSC content in above- ground anthesis biomass.

Wheat stem wall polysaccharide generally composed of lignin (14–21%), hemicellulose (26–35%) and cellulose (34–43%) (Sun *et al.* 2004; Kabel *et al.* 2007). Xue *et al.* (2008) found cellulose and hemicellulose contents in the stem of wheat line (SB169) and (SB165). It was significantly lower in the SB169 lines than in the SB165 lines. Relative difference in carbon partitioning between WSCs and cell wall polysaccharides can be expressed as the ratio of WSCs to hemicellulose plus cellulose (Aspeborg *et al.* 2005; Persson *et al.* 2005). Heat and drought stress during anthesis increased the concentration of cell wall polysaccharide (Hong *et al.* 1989), while high temperature and drought after anthesis decreased the concentration of cell wall polysaccharide (Laurentin & Douglas, 2003). Coles *et al.* (1997) showed that the concentration of cell wall polysaccharide in wheat was increased by mild drought after flowering but decreased under severe drought. High temperature from times of anthesis also increased in cell wall polysaccharide concentration in the stem as well as grain, particularly cell wall polysaccharide (Zhang *et al.* 2010).

2.3.2 Enzymes

Drought and high temperature during grain-filling period affects efficient channeling of carbohydrates from source (green leaf and stem) to sink organs (developing grains), severely impacting biochemical transformation, sucrose metabolism and starch accumulation (Suneja *et al.* 2015). The carbohydrates from photosynthesis after anthesis transport to the grain as sugars such as fructans, sucrose, glucose and fructose are accumulated in the stems as reserves (Pollock 1986; Xue *et al.* 2008) and are generally referred to as water-soluble carbohydrates (WSC) (Gebbing, 2003) are synthesized in the peduncle, penultimate internode and grain through catalysis by a series of enzymes (Wang *et al.* 2007). Sucrose synthase (SuSy), invertase (INV) starch branching enzyme (SBE), starch debranching enzyme (DBE) and ADP-Glucose Pyrophosphorylase (AGPase) are the enzymes involved in sucrose-starch anabolism, and play an important regulating role in starch synthesis and accumulation (Wang *et al.* 2010; Kang *et al.* 2013; Wang *et al.* 2012). These carbohydrates could be potentially remobilized and transported to the developing grains, playing an important role in buffering grain yield under post-anthesis stress since they could potentially contribute more than 20% of the grain yield observed under normal conditions (Blum, 1998; Wardlaw & Willenbrink, 2000). High

temperature followed by drought adversely affects endosperm cell number, grain filling duration, resulting in smaller grains, reduced grain weight and an overall decreased grain yield.

Once the stem reserved sugars (sucrose or fructans) reached to sinks, these degraded into hexoses and hexose derivatives for numerous metabolic and biosynthetic processes (Ruan *et al.* 2010). It is the cleavage of α-glycosidic bond between glucose and fructose that initiates sucrose utilization; and in plants this reaction is catalysed by two enzymes- invertase and sucrose synthase. Plant cytoplasmic alkaline invertases (β-D-fructofuranosidase, pH. 7.0-7.8) constitute a family of enzymes that irreversibly hydrolyse sucrose to glucose and fructose. Invertase have roles in several plant physiological processes related to long-distance nutrient allocation as well as regulating developmental processes, hormone responses and biotic and abiotic interactions (Roitsch & Gonzalez, 2004). A key point of sink organs, such as developing wheat grain and tissue provided with carbon, is utilization of sucrose-universal transport form of sugar, with the involvement of sucrose synthase (Bruskova *et al.* 2009). Sucrose synthase catalyses the first reaction in the reaction sequence of sucrose-starch conversion to form UDP-Glucose and Frutose, which is thought to be the first step in the sucrose-to-starch conversion, therefore, plays a pivotal role in the process of starch biosynthesis. Sucrose synthase, affected adversely and its activity decreased under high temperature stress (Zahedi *et al.* 2003), resulting in decreased sucrose–starch conversion. In wheat stems, activities of both sucrose synthase (Wardlaw & Willenbrink, 1994) and acid invertase (Bancal & Triboï, 1993) have been found to be very high at anthesis and to fall sharply during physiological maturity. SuSy activity parallels the decreases in starch content after high temperature treatment in rice and barley (Cheng *et al.* 2005; MacLeod & Duffus, 1988).

ADP-Glucose Pyrophosphorylase catalyzes the first step in starch synthesis which produces the activated glucosyl donor ADP-glucose from ATP and Glc-1-phosphate. This reaction is generally considered to be the committed step in starch biosynthesis (James *et al.* 2003). The subcellular location of AGPase is not consistent between all higher plants. In cereal endosperm the enzyme is mostly extra-plastidial while in all other plants it is primarily plastidial (Beckles *et al.* 2001). AGPase is one of the enzymes most intensely pretentious by heat and drought in grain filling periods of cereal crops (Linebarger *et al.* 2005), diverse extents of stored starch in grains of different wheat cultivars could be associated with AGPase activities (Johnson *et al.* 2003; Kang *et al.* 2010). Kaur *et al.* in 2017 reported that decrease in AGPase activity in UP2565 (more than 1.5-fold) than WH730 due to combined high temperature and drought stress can be attributed to the corresponding decrease in the starch content and hence grain yield in *var.* UP2565 over WH730.

Starch branching enzymes is one of the primary enzymes of starch biosynthesis, have multiple isoforms existing in the plant kingdom and catalyze the internal cleavage of a α-(1,4) linkages and transfer of the released reducing end to a C-6 hydroxyl group of glucose in a linear

glucan, creating a new α-(1,6) branch linkage. Starch debranching enzymes hydrolyze a-(1,6)-linkages within apolyglucans. This activity is required to regularize the branching and maintain amylopectin crystallinity (Jeon *et al.* 2010). DBEs can selectively remove improperly positioned branches during amylopectin synthesis, thus they have direct functions in amylopectin formation (Nakamura, 2002; James *et al.* 2003). Wei *et al.* (2011) found under natural (timely sown) condition, higher starch branching enzyme activity in superior spikelets than inferiors in rice genotypes in V20 and Zhong 9, whereas that was significantly lower than the latter when encountering heat stress in both genotypes. Water stress with high temperature to cereals alters endosperm starch granule size distribution and amylose content (Singh *et al.* 2008; Fabian *et al.* 2011). The starch from drought-treated wheat (Sheikh *et al.* 2010; Lohot *et al.* 2010) also contains lower amylose due to significantly decreases in the starch branching enzyme and ADP-Glucose Pyrophosphorylase activity.

2.4 Effect of drought and high temperature stress on yield and yield attributes

Grain weight and finally yield depends on the photosynthesis and carbohydrate remobilization from stem to the developing grain. In wheat, the peduncle and the penultimate internode are primary container of most storage carbohydrates (Wardlaw & Willenbrink, 1994), with variations in storage and remobilization under stress environments being more in the peduncle than in penultimate internode (Bonnett & Incoll, 1992). The most reliable traits associated with stress tolerance and higher grain yield under drought and high temperature are, early growth vigor and earliness, plant height, long peduncle and penultimate, more peduncle and penultimate internode dry weight, grain growth rate, grain filling duration, number of spikelets per spike, number of tillers per plant, number of grains per spike, 1000-grain weight, biomass and yield per meter square (Ceccarelli *et al.* 2004; Lopes *et al.* 2013; Ahmed *et al.* 2013; Simova-Stoilova, *et al.* 2016). Drought with high temperature at vegetative to reproductive stage of synthetic hexaploid showed significant reduction in plant height and increased with magnitude of drought < high temperature < combined stress (Pradhan *et al.* 2012).

Under drought stress inhibition of photosynthesis caused more remobilization of soluble carbohydrate in peduncle and penultimate internodes of tolerant cultivars (Saeidi *et al.* 2012). Drought stress significantly reduced peduncle and penultimate length whereas maximum reduction was found in peduncle followed by penultimate internode and third lower internodes (Azhand *et al.* 2015). Maximum weight of the lower internodes, on average, reached 7 days post-anthesis, whereas those of peduncle and penultimate internode reached 14 days after anthesis (Azhand *et al.* 2015). Significant variation was found among the source limitation for peduncle and penultimate dry weight and length (Abdoli *et al.* 2013; Rahman *et al.* 2016). Decrease of stem (peduncle, penultimate and lower internodes) dry weight was found between anthesis and the end of grain filling (Cruz-Aguado *et al.* 2000; Moragues *et al.* 2006).

Maximum peduncle and penultimate dry weight and length was under control condition, whereas drought reduced both dry weight and length (Azhand *et al.* 2015).

Beltrano *et al.* (2006) found that decrease in the grain filling duration (GFD) and a significant reduction in the rate of grain-filling. Wheat genotypes grown in delayed sowing with severe drought stress had the shortest grain filling duration. Wheat genotype Fsd-08 under water stressed soil and tempered environment shows 31, 35, and 38% longer grain filling duration as compared with another genotype at 100–50% field capacity (Ihsan *et al.* 2016). Kobata *et al.* (1992) and Beltrano *et al.* (2006) found that a water stress imposed at anthesis, or over the first few days after anthesis, affects grain set and the grain filling rate, causing a reduction in yield components. Laxman *et al.* 2014 found a positive correlation of grain growth rate at 14, 28 and 35 days after anthesis with grain weight in normal sowing and in late sowing wheat genotypes.

The rate of cereal grain yield varied in dependences of yield attributes *viz*. stem height, spike length, number of spikelets per spike and number of grain per spike were strongly associated with the vegetative growth period (Ali *et al.* 2010; Knezevic *et al.* 2012; Munjal and Dhanda, 2016). These constituents are in direct associate with productivity in wheat (Knezevic *et al.* 2007) which is strongly influenced by the drought, heat and combined effects of these stresses. Morpho-physiological parameters such as total number of tiller, spike number per m^{-2}, grain number per spike, number of fertile tillers per plant, 1000 grain weight, peduncle and penultimate internode length, awn length, stem weight, grain weight per spike, spike weight showed maximum reduction due soil moisture reduction and increasing environmental temperature (Rajala *et al.* 2009; Kiliç & Yagbasanlar, 2010).

Continuous rise in environmental temperature and changes in rainfall patterns had direct effects on biomass, test weight, grain weight per spike and ultimately on crop yield have been reported by Challinor *et al.* (2009); Long & Ort, (2010); Prasad *et al.* (2011); Munjal & Dhanda, (2016) and Dhanda & Munjal, (2017). Wajid *et al.* (2011) reported that yield attributes of two wheat genotypes with stress at boot and anthesis stage number of grains per spike, biomass, grain yield and harvest index declined to a greater extent when drought stress was imposed at anthesis. Ram *et al.* (2017) found reduction in wheat grain yield and physiological parameters under combined effects of high temperature and drought. Results revealed that the ratio Fv/Fm of chlorophyll fluorescence, chlorophyll content and canopy temperature were the most effective parameters to select for tolerant genotype with more grain yield in water limited delayed showing condition. The reduction in yield and yield attributes due to combined effect of drought and high temperature stresses in both durum and bread wheat was observed by Singh *et al.* (2014).

Heat and drought often happen simultaneously under field conditions, particularly at the end of the growing season. The combined effect of heat and drought on crop yield is considerably higher than each effect individually (Savin and Nicolas, 1996; Sunita *et al.* 2017;

Dhanda and Munjal, 2017). The combination of heat and drought during grain filling increased the water use efficiency of wheat, although the grain yield was reduced (Aprile *et al.* 2013). The yield reduction was mainly caused by the shortening of the grain filling period due to high temperature and it was not as affected by drought stress (Wardlaw, 2002). High temperature and drought during grain filling stage shortened the grain filling duration and reduced grain weight and test weight (Ehdaie *et al.* 2006; Kaur *et al.* 2008). Kaur & Behl in 2010 also found that interaction of high temperature and drought resulted in maximum reduction in grain yield in UP2565 (33%) than WH730 (13%). The interactions showed that productivity of wheat is reduced significantly more under combined stresses than stress alone due to reduction in photosynthetic processes (Shah & Paulsen, 2003).

CHAPTER-III

MATERIAL AND METHODS

The present investigation was aimed at the "**Studies on carbohydrate metabolism in wheat under drought and high temperature conditions".** The experiment was conducted in the field and laboratory of the Wheat and Barley section, Department of Genetics and Plant Breeding, College of Agriculture, CCS HAU, Hisar.

3.1 MATERIAL

3.1.1 Plant Material

Seeds of following eight wheat genotypes differing in their sensitivity to drought and high temperature were procured from Indian Institute of Wheat and Barley Research (IIWBR), Karnal and Wheat and Barley Section of Department Genetics and Plant Breeding, CCS HAU.

Genotypes

1. AKAW-3717	3. DHTW-60	5. HTW-11	7. WH-730
2. C-306	4. HD-2967	6. KUNDAN	8. WH-1105

3.1.2 Chemicals

All the chemicals used in the present investigations were of analytical grade (AR) and were from Sigma Chemicals Co., USA, Hi-Media, Sisco Research Laboratories (SRL) and E. Merck, Bombay.

3.2 METHODS

3.2.1 Raising of crop

The crop was raised in normal, late and very late sown conditions under irrigated and drought condition. Drought was created by withholding the irrigation at different stages (40 days after sowing (DAS), 65 DAS, 40+65 DAS and for complete drought no irrigation was given). In late sown conditions, sowing was delayed by one month from the normal sowing and for very late sown conditions, sowing was delayed by one month from the late sowing. The experiment was laid out in RBD with three replications. The details of experiment are given below:

Plot size	:	2 m × 0.90 m (4 row of 2m length with 22.5 cm apart)		
Experimental Design	:	RBD (Randomized Block Design)		
Replication	:	Three		
Sowing Time	:	Timely Sown	:	17 November, 2015; 13 November, 2016
		Late Sown	:	14 December, 2015; 16 December, 2016
		Very late Sown	:	13 January, 2016; 11 January, 2017
Treatment	:	Control (Irrigated)		
		Complete drought (No irrigation throughout the crop season by withholding irrigation)		
		Drought at 40 days after sowing		
		Drought at 65 days after sowing		
		Drought at 40 + 65 days after sowing		

3.2.2 Geographic site and weather

Experimental site was located at the farm area of Wheat and Barley section, Department of Genetics and Plant Breeding, College of Agriculture, CCS HAU, Hisar. It is situated at $29^0$10' N latitude, $75^0$46' E longitude and at latitude of 215.2 meters above mean sea level. The weather conditions data during the crop season (November to April) was taken from Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar and the weekly average is presented in Figure 1and 2.

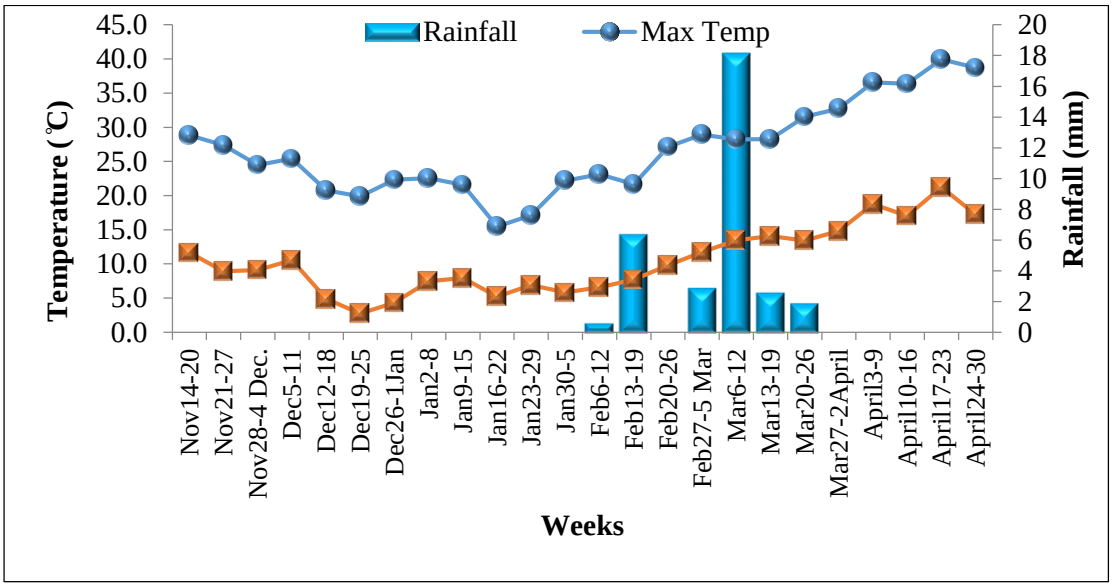


Figure 1. Weekly maximum, minimum temperature (°C) & rainfall (mm) during crop seasons of 2015-16

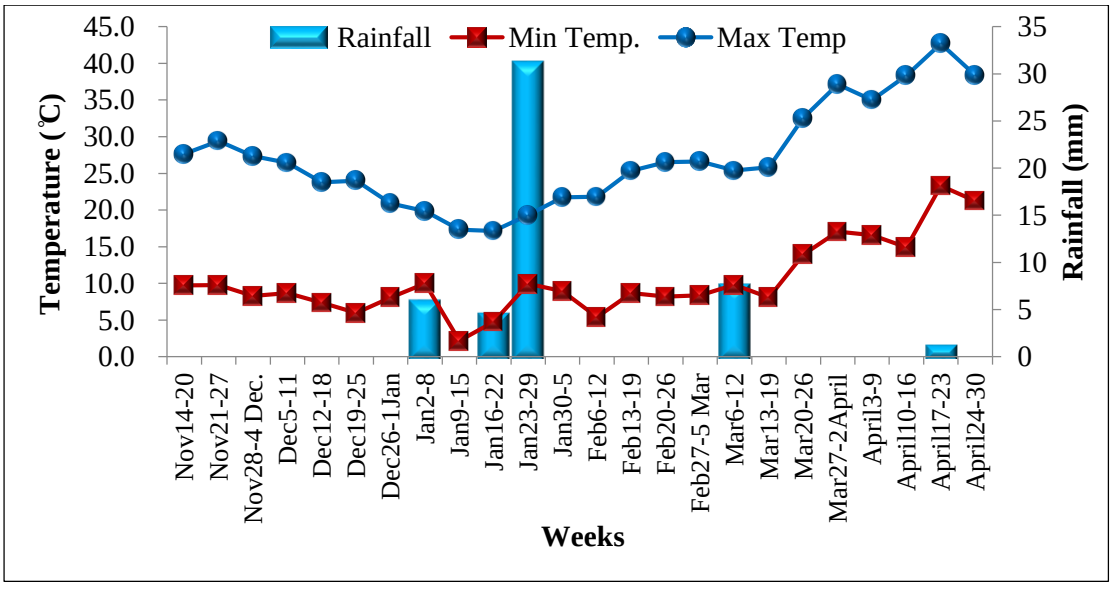


Figure 2. Weekly maximum, minimum temperature (°C) & rainfall (mm) during crop seasons of 2016-17

OBSERVATIONS RECORDED

The observation for various physiological and biochemical parameters were recorded at two stages *i.e*., anthesis and 15 days after anthesis. The data was recorded on three plants per genotype.

3.3 PHENOLOGICAL PARAMETERS

3.3.1 Days to Heading

It was calculated as days taken from sowing to emergence of 75 % of spikes in a plot.

3.3.2 Days to Anthesis

It was calculated as days taken from sowing to appearance of 75 % anther in 75% of plants in a plot.

3.3.3 Days to Physiological Maturity

It was calculated as days taken from sowing to maturity when 75 % of plant in plot showed natural senescence.

3.4 PHYSIOLOGICAL PARAMETERS

3.4.1 Osmotic Potential

The osmotic potential of leaf was estimated by the method of Morgan (1980) with psychrometric technique using a model VAPRO 5520 vapour pressure osmometer (Wescor INC., Lorganan, Utah, USA). The leaf was excised, sealed in an ependorff tube individually and quickly frozen at -20 ºC. Before measuring the osmotic potential, the sample was thawed for 60 min. at 25 ºC. The sample was then transferred into 2 ml capacity syringe and collected the sap by pressing the plunger to squeeze out sap. The filter paper disc was placed on the sample holder of the instrument, applied 10 µl of the extracted leaf sap, pushed the holder inside the chamber and locked it. About 80 seconds later the osmotic potential reading displayed on the digital screen was recorded. The osmometer was calibrated by using standard solutions of NaCl. Osmotic potential value obtained from the osmometer was in mmol kg^{-1}, which was converted to MPa (pressure unit) according to the equation:

OP (MPa) = (-R × T × osmometer reading) / 1000

Where:

R is the gas constant (0.008314) and T is the laboratory temperature measured on the Kelvin scale (T = 298K).

3.4.2 Water Potential

Water potential of leaf was measured by the method of Turner & Long, (1980) with the help of pressure chamber (Model 3005, Soil Moisture Equipment Corporation, Santa Barbara, CA, USA) between 8 AM to 10 AM. The flag leaf was excised with the help of sharp edged knife and sealed in the pressure chamber one by one with the cut end protruding outside. Cut end of the flag leaf was observed using a magnifying glass whilst the chamber pressure slowly increases. At the point when water is observed arising at the cut end of the leaf, gas valve was

closed and pressure shown on the pressure gauge was recorded. This pressure (-bar) was recorded as water potential and the calculation were done as following formula.

-10 bar = -1MPa

3.4.3 Relative Water Content

Relative water content (RWC) was measured by the method of Barrs & Weatherley, (1962). Leaf samples were excised, weighed immediately and placed them in petriplates containing about 20 ml of distilled water at constant temperature in diffused light for 6 hours. When leaves became fully turgid, the samples were taken out from petriplates; adhered water was blotted off with rough filter paper and reweighed for turgid weight. Then samples were kept for oven dry at 70 ºC for 48 hrs and dry weight was recorded.

RWC was calculated by the following formula:

$$\text{RWC } (\%) = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} \times 100$$

3.4.4 Chlorophyll Fluorescence

The chlorophyll fluorescence was measured by following the method of Fracheboud (2006), where measurements of F_0, F_m and Fv/Fm were taken about 4 cm from the base of abaxial surface of flag leaf using a hand-held chlorophyll fluorescence meter (modal no. Opti-Sciences OS-30P). Five readings were taken from three randomly selected plants. It works on the principle of continuous excitation fluorescence. The fully expanded leaves were first acclimated to the dark for 20 min. by fixing clips. The dark adapted samples were continuously irradiated for 1 sec, provided by an array of 3 light emitting diodes in sensor. The florescence signals were detected as F_o, F_m and Fv/Fm. Data was recorded between 10:00 AM to 12:00 PM.

3.4.5 SPAD-Chlorophyll Content

The SPAD chlorophyll content was measured by the method of Yadava (1986), by using the chlorophyll meter (model no. Minolta SPAD-502 Plus) to measure the relative chlorophyll content of leaves. The meter makes instantaneous and non-destructive readings on a plant, based on the quantification of light intensity (peak wavelength: approximately 650 nm with red light emitting diode) absorbed by the tissue sample.

3.4.6 Stem Reserve Mobilization

Stem reserve mobilization was calculated by the method suggested by Cox *et al.* (1986). Five stems (penultimate & peduncle without spike) from randomly selected plants from each plot at anthesis and maturity were separated into penultimate and peduncle and were dried in an oven at 80 °C for 72 hrs. The weight of stem parts was recorded with the analytical balance (Afcoset, ER-200A) and stem reserve mobilization was calculated using following formula.

$$\textbf{SRM } (\%) = \frac{\text{DMSHT (Ant)} - \text{DMSHT (Mat)}}{\text{DMSHT (Ant)}} \times 100$$

SRM is stem reserve mobilization (g/plant); DMSHT (Ant) is above-ground dry matter of stem parts at anthesis stage (g); DMSHT (Mat) is aboveground dry matter of stem parts at maturity stage (g). SRM from stem part (penultimate and peduncle) was calculated separately.

3.5 BIOCHEMICAL ANALYSIS

Plants were tagged at the time of anthesis and stem (peduncle and penultimate) samples were collected at two stages (anthesis and 15 days after anthesis). Enzymatic and non-enzymatic traits were carried out under laboratory conditions in wheat physiology laboratory, Department of Genetics and Plant Breeding and Department of Botany and Plant Physiology, CCSHAU, Hisar.

3.5.1 Biochemical Metabolites

3.5.1.1 Enzymatic determination of glucose, fructose and sucrose

Enzymatic determination of glucose, fructose and sucrose is based on UV detection of NADP, which is product of glucose-6-phosphate oxidation. These sugars are enzymatically converted into glucose-6-phosphate prior to be Oxidized $NADP^+$ which is reduced to NADPH. The increase in NADPH concentration can be read at 340nm. Enzymatic determination of glucose, fructose and sucrose was assayed by the method of Baumann & Gierschner, (1971).

Reagents

1. **0.2M imidazole buffer pH.7.6 including 10mM $MgCl_2$:** Dissolve 13.62g of imidazole and 2.033g $MgCl_2$ in 800 ml dH_2O; and fill up to 1000ml with deionized water.
2. **0.05M sodium citrate buffer pH 4.6:** 0.1M solution of citric acid and 0.1 sodium citrate; mix 25.5ml of citric acid solution with about 22ml of sodium citrate solution in 25ml of water; adjust the pH using sodium citrate solution and fill up with water to 100ml.
3. **Invertase (b-D-fructofuranosidase) 200 U/ml in sodium citrate buffer:** Dissolve adequate amount invertase responding to 4000U of invertase activity in 20ml sodium citrate buffer pH 4.6.
4. **16mM $NADP^+$:** Dissolve into 12ml water; divide into 1 ml aliquots; store at refrigerator.
5. **Glucose-6-phosphate dehydrogenase (212U /ml)/225mM $MgSO_4$:** Dissolve adequate amount of Glucose-6-phosphate-DH (500 U of DH) and 55.5 mg $MgSO_4 \times 7$ H_2O in 2.25 ml 55% glycerol solution.
6. **Phosphoglucose Isomerase (PGI) (1000U/ml)**: Dissolve adequate amount PGI responding to 1000U of PGI activity in 2.25 ml of 50% glycerol solution.

Extraction

Extract for analysis was prepared by crushing 2g of oven dried stem sample (72 hrs at 75^0C) in 80% ethanol using pastel mortar. The resulting extract was centrifuged for 15 min at 5000 rpm (4°C). The supernatant was stored at -20°C until required for analysis.

Procedure

Four glass test tubes was putted into rack and marked as: I (blank for sucrose sample), II (sucrose sample), III (blank for glucose-fructose sample), IV (glucose-fructose sample). Then 200µl of invertase was pipetted into tube I and II. 100µl supernatant was pipetted into tube II and IV and mixed using vortex shaker and incubate the tubes for 5 minutes at room temperature and final volume of 2.2 ml, was made adding distilled water in each test tube. 100µl of 0.2M imidazole buffer and 100µl of 16mM $NADP^+$ was added in each tube. Mixed sample using the vortex shaker, waited for 3 minutes and absorbance was read at 340nm (A_1). Then 200µl of G-6-P-DH was added to each test tube, mixed using vortex shaker, waited for 5 minutes and absorbance was read at 340nm (A_2). In tubes III and IV 100µl phosphoglucose isomerase (PGI suspension was added. Mixed sample using the vortex shaker, waited for 10 minutes and absorbance was read at 340nm (A_3).

Calculation

Absorbance (nm)

Absorbance of free glucose ($A_{Glucose}$), free fructose ($A_{Fructose}$) and sucrose ($A_{Sucrose}$) was calculated from following equation:

$A_{Glucose} = (A_{2\,IV}-A_{1\,IV})-(A_{2\,III}-A_{1\,III})$

$A_{Fructose} = (A_{3\,IV}-A_{2\,IV})-(A_{3\,III}-A_{2\,III})-(A_{3I}-A_{2\,I})$

$A_{Sucrose} = ([A_{1\,II}+A_{2\,II}+A_{3II})]-[A_{1I}+A_{2I}+A_{3I}]-[A_{1\,IV}+A_{2\,IV}+A_{3\,IV}]-[A_{1\,III}+A_{2II}+A_{3\,III}])$

I, II, III, IV= Test tube numbers

Calculate the concentration of each sugar using the following equation:

Concentration (gl^{-1}) $= (V \times MW) - (\varepsilon \times d) \times v \times A$

Where,

V= Total volume of Sample, MW= Molecular Weight, ε= Extinction coefficient (ε of NADPH at 340nm is 6300), d= Path length, v= Analyzed sample volume and A= Absorbance

For Glucose $= 0.0286 \times V/v \times A_{Glucose}$

For Fructose $= 0.0286 \times V/v \times A_{Fructose}$

For Sucrose $= 0.0543 \times V/v \times A_{Sucrose}$

3.5.1.2 Stem Cell Wall Polysaccharide (Cellulose)

Stem cell wall polysaccharide (cellulose) was determined by the method of Updegroff, (1969). Cellulose undergoes acetolysis with acetic/nitric reagent to form acetylated cellodextrins which get dissolved and hydrolyzed to form glucose units on treatment with 67%

H_2SO_4. On dehydration with H_2SO_4, glucose forms 5-hydroxymethyl furfural which on reaction with anthrone gives a green coloured product. The colour intensity can be measured at 630 nm.

Reagents

1. **Acetic/nitric reagent:** Mix 150 ml of 80% acetic acid with 15 ml of conc. HNO_3.
2. **Anthrone reagent:** 200 mg anthrone / 100 ml of conc. H_2SO_4 (Prepare fresh and chill for two hours before use).
3. **67% H_2SO_4**
4. **Standard cellulose solution:** Add 100 mg of cellulose in 10 ml of 67% H_2SO_4 and leave for 1h. Dilute 1 ml of the solution to 100 ml (100µg/ml).

Procedure

To about 0.5-1.0 g of sample, added 3 ml of acetic: nitric reagent and mixed using a vortex mixer. Placed in a water bath at 100ºC for 3 min. Cool and centrifuged for 15-20 min. Supernatant was discarded. Residue was washed with water, then added 10 ml of 67% H_2SO_4 and left it for 1 h at room temperature. Diluted 1ml of this solution to 100ml and 1ml of the diluted solution, add 10 ml of anthrone reagent and mixed well. Heated the tubes in a boiling water bath for 10 min, cooled and measured the absorbance at 630 nm. Blank was prepared with anthrone reagent and water. The amount of cellulose in the sample was determined from the standard curve prepared by taking 0.4 to 2ml of standard cellulose solution (corresponding to 40-200 µg of cellulose).

3.5.1.3 Total Water Soluble Carbohydrate

Total water soluble carbohydrates were estimated by the method of Yemm & Willis (1954).

Reagents

1. **Anthrone reagent:** 400mg anthrone / 100 ml of conc. H_2SO_4 (Prepare fresh)
2. **80% Ethanol**
3. **Conc. H_2SO_4**

Extraction:

Extraction of soluble carbohydrates was done according to Barnett & Nayler's (1966) procedure. 100mg of fresh material was finely ground by using pestle and mortar then extracted with 2 ml of 80% ethanol (v/v) on a water bath at 50± 1ºC for 15minutes. It was cooled and centrifuged at 5000 rpm for 30 minute. The supernatant (extract) was kept aside and the pallet re-extracted twice with 80% ethanol. Total volume of extract was made 5ml. with 80% ethanol.

This extract was used for the analysis of soluble carbohydrates. The residue was used for starch estimation.

Procedure

Ethanolic extract measuring 0.1 ml was evaporated to dryness in a test tube. After cooling, the residue was dissolved in 1 ml of distilled water, and to it 4 ml of anthrone reagent

was added. The mixture was then heated in a water bath for ten minutes. After cooling, optical density was recorded at a wavelength of 620 nm against reagent blank. For standard a range of concentration (20-100µg/ml) of D-glucose were used.

3.5.2 Biochemical enzymes

A. Preparation of enzyme extract

Extraction conditions were standardized with respect to molarity and pH of buffer to achieve maximum extraction of enzymes in stem (peduncle and penultimate). Peduncle and penultimate internode samples collected at two stages (anthesis and 21 days after anthesis) was used for preparation of enzyme extract. 500 mg of stem sample (peduncle and penultimate) were hand homogenized in a prechilled pestle and mortar at 4 °C with chilled 2 ml of buffer on ice. The homogenate so obtained was centrifuged at 10,000 rpm for 20 min in a refrigerated centrifuge at 4 °C. The supernatant was carefully decanted and used as crude enzyme preparation. The observations were recorded in triplicate and mean of the three readings was taken. Protein in the enzyme extract was measured by the method of Lowry *et al.* (1951) and the enzyme activity is expressed on the basis of per mg protein. The extraction buffer employed had following composition as follows.

B. Reagents for extraction buffer

50 Mm	:	3-(N-morpholino) propane sulphonic acid (MOPS) pH 7.4
2 mM	:	$MgCl_2$
1 mM	:	EDTA
2 mM	:	Dithiothritol (DTT)

C. Enzyme Assays

3.5.2.1 Sucrose Synthase (EC 2.4.2.13)

Sucrose synthase was assayed by the method of Shannon & Dougherty (1972). One ml of reaction mixture containing UDP (1 µmole), sucrose (25 µmole) and MES buffer (pH 6.5, 60 µmole) was incubated with 0.2 ml of enzyme preparation at 37 °C for 15 min. The reaction was terminated by placing the reaction mixture in boiling water bath for 2 min. Released fructose was measured by Somogyi's modified method (Somogyi, 1945) and absorbance was read at 520 nm. One unit of enzyme activity is defined as the amount of 1.0 nmole fructose released in per minute under assay conditions.

3.5.2.2 Invertase (EC 3.2.1.26)

Invertase was assayed by the method of Leigh *et al.* (1979). One ml of reaction mixture containing phosphate buffer (pH 7.5, 20mM) and sucrose (25 µmole) was incubated with 0.1 ml of enzyme extract at 33 °C for 15 min. The reaction was terminated by adding 1 ml of copper reagent and placing the reaction mixture in boiling water bath for 20 min. Cooled and 1 ml of arsenomolybdate reagent was added. Final volume 25 ml was made by using distilled water

and absorbance was read at 520 nm. One unit of enzyme activity is defined as the 1.0 nmole of sucrose hydrolyzed to invert sugar per minute under assay conditions.

3.5.2.3 ADP glucose pyrophosphorylase (EC 2.7.7.27)

AGPase was assay in the reverse direction by modified method of Kleczkowski *et al.* (1993). The reaction mixture contained.

Reagents	**Final concentration**	**Volume in 1 ml reaction**
50 mM MOPS (pH 7.4)	1.06 g/30 ml	495 µl
7.5 µ mole $MgSO_4.7H_2O$	18.45 mg/ml	100 µl
Enzyme extract	100 µl	100 µl
3 µ mole 3-PGA	6.912 mg/ml	100 µl
0.5 µ mole $NADP^+$	3.827 mg/ml	100 µl
0.5 µ mole ADP-glucose	3.166 mg/ml	100 µl
Phosphoglucomutase	2 units	3 µl
Glucose-6-phosphate dehydrogenase	2 units	2 µl

The reaction was started by the addition of 200 µl of sodium pyrophosphate (2.5µmole). The pyrophosphorolytic activity of AGPase was assayed spectrophotometrically by monitoring the increase in absorbance due to conversion of NADP to NADPH at 340 nm. One unit of AGPase activity is defined as the amount of enzyme that catalyzes the formation of 1.0 nmole of ADP-glucose per min at 75 under assay conditions.

3.5.2.4 Starch Branching Enzyme (EC 2.4.1.18 α-1, 4-glucan-6-glucosyl transferase)

Decrease in the absorbance of iodine-amylose complex after incubation of enzyme extract with amylose, provided a measure of the activity of starch branching (Q) enzyme (Hawker and Downton, 1974). The reaction mixture (1.5 ml) containing sodium citrate, 100 µmole; amylose, 300 µg and enzyme extract, 0.1 ml was incubated at 30 °C for 15 min. The reaction was stopped by the addition of 0.5 ml of 2 N HCl followed by the addition of 1 ml of iodine reagent. The iodine reagent was prepared by freshly mixing 0.5 ml of iodine stock solution (6 g KI and 600 mg I2 in 100 ml of water) to 50 ml of 0.05 N HCl. Water was added to the reaction mixture to give a final volume of 5 ml. The absorbance of the amylose-iodine complex was read at 590 nm. One unit of starch branching enzyme activity is defined as 1 nmol of D-glucose incorporation into α D-glucan per min under assay conditions.

3.5.2.5 Starch Debranching Enzyme (EC 3.2.1.10)

Assay for debranching enzyme was made with amylopectin as substrate according to the procedure of Briggs (1961) as employed by Baun *et al.*, 1970. Enzyme extract (0.2 ml) was incubated with reaction mixture containing 1 ml of amylopectin (3 mg/ml) and 0.5 ml of 0.05 M tris-maleate buffer (pH 6.6) containing 0.007 M EDTA. After terminating the reaction by

0.5 ml of 2 N HCL, 1ml of iodine reagent was added and volume made to 5 ml with water. Enzyme activity was based on the decrease in absorbance of the iodine-amylopectin complex at 540 nm. One unit of starch branching enzyme activity is defined as 1 nmol of D-glucose released per min under assay conditions.

3.6 YIELD AND YIELD ATTRIBUTES

3.6.1 Plant height (cm)

The plant height of three plants from each genotype per replication was recorded at maturity, as the length measured from its base up to the apex of plant excluding awns in cm and average was recorded.

3.6.2 Peduncle length and dry weight

The peduncle (first interned having spike) length (cm) and dry weight (g) (oven dry for 4-5 days at 80 ^{o}C) were measured at maturity in the main tiller from five randomly selected plants of each genotype.

3.6.3 Penultimate internode length and dry weight

The penultimate internode (second internode after spike) length (cm) and dry weight (g) (oven dry for 4-5 days at 80 ^{o}C) were measured at maturity in the main tiller from five randomly selected plants of each genotype.

3.6.4 Grain growth rate

Grain growth rate estimated by the method Zahedi & Jenner (2003). Spikes were tagged after seven days of anthesis (anthers extruded in approximately 75 % of the spikes) and used to estimate the grain growth rate. Five spikes were sampled from each treatment at 7 day intervals from tagging up to harvest. Ears were threshed by hand. Grain dry mass was determined on five spikes after oven-drying at 80°C. The weight of hand threshed kernels was determined with the analytical balance (Afcoset, ER-200A).

$$\mathbf{GGR} = \frac{(W2 - W1)}{(T2 - T1)}$$

Where,

W_1= Grain dry weight at initial time
W_2= Grain dry weight at final time
T_1= Initial time
T_2= Final time

3.6.5 Grain filling duration

Grain filling duration (GFD) was measured as interval between the date of anthesis and physiological maturity.

3.6.6 Number of spikelets per spike

The total number of spikelets/spike was counted at maturity from five main spikes of each genotype per replication.

3.6.7 Spike length (cm)

The spike length was recorded in cm at maturity in the main spike from five randomly chosen plants of each genotype per replication excluding awns and average was worked out.

3.6.8 Number of productive tillers per square meter

Fully developed spikes bearing tillers per square meter were counted at maturity and average was recorded.

3.6.9 Biomass (g) per square meter

Plants were cut from the base of stem at maturity and weight of plants in per meter square was taken using spring balance in grams and average was taken.

3.6.10 Number of grains per spike

Total numbers of grains in five spikes in each replication were counted at the time of harvest and average of five was recorded.

3.6.11 Grain weight (g) per spike

The weight of total grains per spike from five spikes in each replication was taken in grams and average of five was recorded.

3.6.12 Grain yield (g) per square meter

Grain yield was recorded after harvesting and threshing the plants in per meter square. The threshed grains were cleaned and yield was recorded in gram.

3.6.13 1000 grain weight (g)

Weight of randomly chosen clean and filled 1000 grains was measured in grams from each replication using electronic balance and average was recorded.

3.6.14 Susceptibility index for grain yield (SI)

Susceptibility index for grain yield (SI) was calculated over stress and non-stress environment. The SI of individual genotype was calculated by the method suggested by Fisher & Maurer (1978) with the following formula:

$$\textbf{SI for grain yield} = (1-Y/Y_P)/D$$

Where,

$D = 1- X/X_P$

Y and YP is grain yield for individual genotypes under stress and normal environment, respectively. X and X_P, represents mean grain yields of all genotypes under stress and normal environment, respectively.

3.7 SOIL MOISTURE

The soil samples of 75-100 g from five environmental conditions (Control, Complete drought, drought 40 DAS, drought 80 DAS and Drought at 40+80 DAS) were collected at a depth of 15, 30 and 45 cm by using soil auger, the samples was taken as quickly as possible and stored in aluminium boxes, fresh weight of the samples were measured, dried the samples

in oven at 105ºC for 24 hours, measured the dry weight of the samples and soil moisture content was calculated according to Ge *et al.* (2012) using the following formula:

$$\textbf{Soil Moisture}\ (\%) = \frac{(\text{Soil fresh weight} - \text{Soil dry weight})}{(\text{Soil dry weight})} \times 100$$

3.8 Statistical analysis

The data was analyzed by analysis of variance for the randomized block design (RBD) using OPSTAT software available on www. http// hau. ernet.in home page (Sheoran *et al.* 1998) where each observation was replicated thrice and CD at 5 % was calculated.

The present investigation was carried out to study carbohydrate metabolism in wheat under drought and high temperature conditions. Eight wheat genotypes (AKAW-3717, C-306, DHTW-60, HD-2967, HTW-11, KUNDAN, WH-730 and WH-1105) were evaluated for physiological traits and carbohydrate metabolism under different time of drought [Irrigated (control), D40 (drought at 40 days after sowing), D65 (drought at 65 days after sowing), D40+D65 (drought both at 40 and 65 days after sowing) and complete drought (no irrigation was given throughout season)] with three sowing conditions (timely, late and very late) in randomized block design with three replications at the experimental area of Wheat and Barley section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. The results pertaining to the study undertaken are given below under the following heads:

4.1 Crop phenological parameters
4.2 Physiological parameters
4.3 Biochemical parameters
4.4 Yield and yield attributes
4.5 Soil moisture

4.1 CROP PHENOLOGICAL PARAMETERS

The phenological parameters like days to heading, days to anthesis and days to physiological maturity observed during to two *rabi* crop seasons of 2015-16 & 2016-17 and pooled mean data are presented.

4.1.1 Days to heading

The significant reduction in days to heading in all genotypes along with time of drought application and delayed sowing condition are shown in Table 1. Drought created at different days after sowing reduced the days to heading in late and very late sown conditions and maximum days to heading were found in control (irrigated) condition (91.0) under timely sown condition and minimum days to heading were observed in compete drought stress (64.2) under very late sown condition.

Average days to heading for different drought stress condition varied from 82.2 to 91.0 (timely sown), 76.4 to 83.1 (late sown) and 64.2 to 69.7 (very late sown). The drought given at 65 days after sowing (D65) and D40+D65 and complete drought resulted in significant reduction in days to heading (84.5, 84.0 and 82.2) respectively under timely sown condition, however under late and very late sown condition significant reduction for early heading was observed in complete drought condition only (76.4 and 64.2).

Significant difference was found in all genotypes and different drought stress condition whereas, no significant difference was observed among drought and genotypes interaction under timely sown and late sown condition but very late sown condition showed significant interaction effect for drought and genotypes (Table 1).

Table 1. Response of wheat genotypes to drought and high temperature for days to heading under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	94.7	93.3	87.0	88.0	85.0	**89.6**	88.7	86.0	84.0	81.7	81.3	**84.3**	75.3	73.0	71.3	71.0	71.0	**72.3**
C-306	92.7	90.0	83.7	85.3	83.3	**87.0**	85.0	80.3	79.3	79.7	79.7	**80.8**	74.3	73.0	70.7	69.7	69.3	**71.4**
DHTW-60	90.0	86.0	83.0	82.7	81.0	**84.5**	80.7	73.3	74.3	72.0	71.0	**74.3**	63.7	62.7	59.7	57.7	57.7	**60.3**
HD-2967	86.7	85.3	83.0	81.0	80.3	**83.3**	80.3	78.7	77.3	75.0	73.3	**76.9**	66.3	67.3	65.7	66.0	58.0	**64.7**
HTW-11	93.3	90.0	87.3	84.0	83.0	**87.5**	81.0	79.3	78.7	79.7	72.3	**78.2**	68.3	68.3	66.3	66.3	61.0	**66.0**
KUNDAN	90.0	88.0	84.3	84.0	82.7	**85.8**	82.3	80.3	79.0	79.7	78.0	**79.9**	68.7	69.0	67.0	67.3	64.3	**67.3**
WH-730	93.7	90.0	86.3	87.0	84.0	**88.2**	86.3	82.7	81.0	80.7	81.0	**82.3**	72.3	72.7	69.3	68.7	68.3	**70.3**
WH-1105	86.7	85.0	81.3	80.0	78.0	**82.2**	80.7	79.7	77.7	78.0	74.7	**78.2**	68.3	68.7	66.7	67.0	64.0	**66.9**
Mean (D)	**91.0**	**88.5**	**84.5**	**84.0**	**82.2**	**86.0**	**83.1**	**80.0**	**78.9**	**78.3**	**76.4**	**79.4**	**69.7**	**69.3**	**67.1**	**66.7**	**64.2**	**67.4**
CD at 5%	**D= 1.33, G= 1.17 DxG= NS**						**D= 1.21, G= 1.57, DxG= NS**						**D= 0.98, G= 1.24, DxG= 2.77**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 2. Response of wheat genotypes to drought and high temperature for days to anthesis under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	102.0	99.7	95.3	95.0	94.0	**97.2**	95.7	94.7	90.3	89.7	87.7	**91.6**	80.0	76.7	77.0	75.7	75.0	**76.9**
C-306	98.0	98.0	93.0	92.0	92.3	**94.7**	92.0	93.7	86.7	85.7	86.0	**88.8**	78.0	76.0	74.7	74.0	74.0	**75.3**
DHTW-60	94.7	93.0	92.0	91.0	91.0	**92.3**	84.0	85.3	76.3	76.7	74.0	**79.3**	67.7	67.3	64.0	61.3	61.0	**64.3**
HD-2967	94.0	93.0	89.0	87.0	85.0	**89.6**	86.0	87.0	82.0	80.3	76.3	**82.3**	70.0	70.0	69.0	69.0	60.7	**67.7**
HTW-11	99.0	98.3	94.0	93.0	91.7	**95.2**	87.0	87.7	84.0	85.0	76.7	**84.1**	73.0	72.0	72.3	70.0	63.3	**70.1**
KUNDAN	97.3	95.0	93.0	92.0	91.7	**93.4**	88.0	90.0	86.3	86.0	82.0	**86.5**	74.0	74.0	72.7	73.3	68.0	**72.4**
WH-730	102.0	99.0	94.0	93.7	92.0	**96.1**	93.7	93.0	87.3	87.3	85.7	**89.4**	77.0	75.7	73.7	72.7	74.0	**74.6**
WH-1105	93.0	93.0	87.9	87.4	83.0	**88.9**	86.0	87.7	83.7	83.0	79.0	**83.9**	74.0	73.0	73.0	71.0	69.0	**72.0**
Mean (D)	**97.5**	**96.1**	**92.2**	**91.3**	**90.1**	**93.4**	**89.1**	**89.9**	**84.6**	**84.2**	**80.9**	**85.7**	**74.2**	**73.1**	**72.1**	**70.9**	**68.1**	**71.7**
CD at 5%	**D = 1.30, G= 1.65, DxG= NS**						**D = 1.30, G= 1.64, DxG= NS**						**D = 1.25, G= 1.59, DxG= 3.53**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Average days to heading for genotypes ranged from 82.2 to 89.6 (timely sown), 74.3 to 84.3 (late sown) and 60.3 to 72.3 (very late sown). Genotype WH-1105 (82.2) followed by HD-2967 (83.3) had earliest day to heading under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (74.3) and HD-2967 (76.9) followed by WH-1105 (78.2) had earliest day to heading under late sown condition and genotypes DHTW-60 (60.3) and HD-2967 (64.7) followed by HTW-11 (66.0) under very late sown condition. Genotype AKAW-3717 showed maximum average days to heading among genotypes under all drought and delayed sowing conditions.

4.1.2 Days to anthesis

Days to anthesis showed significant reduction in all genotypes along with time of drought application and delayed sowing condition (Table 2). Drought application reduced the days to anthesis in timely, late and very late sown conditions and maximum days to anthesis were found in control (irrigated) condition (97.5) under timely sown condition and minimum days to anthesis were observed in compete drought stress (68.1) under very late sown condition.

Average days to anthesis for different drought stress condition ranged from 90.1 to 97.5 (timely sown), 80.9 to 89.1 (late sown) and 68.1 to 74.2 (very late sown). The drought situation of D65, D40+D65, and complete drought resulted significant reduction in days to anthesis (92.2, 91.3 and 90.1) respectively, under timely sown condition, however under late and very late sown condition significant reduction for early anthesis was observed in D40+D65 (84.2 and 80.9) and complete drought (70.9 and 68.1) condition.

Significant difference was found for days to anthesis in all genotypes and different drought stress condition whereas, no significant difference was observed among drought and genotypes interaction under timely sown and late sown condition but very late sown condition showed significant interaction effect for drought and genotypes.

Average days to anthesis for genotypes ranged from 88.9 to 97.2 (timely sown), 79.3 to 91.6 (late sown) and 64.3 to 76.9 (very late sown). Genotype WH-1105 (89.5) followed by HD-2967 (89.6) had earliest days to anthesis under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (79.3) and HD-2967 (82.4) followed by WH-1105 (83.9) had earliest day to anthesis under late sown condition and genotypes DHTW-60 (64.3) and HD-2967 (67.7) followed by HTW-11 (70.1) under very late sown condition. Genotype AKAW-3717 showed maximum average days to anthesis among all genotypes under all drought and delayed sowing conditions.

Table 3. Response of wheat genotypes to drought and high temperature for days to physiological maturity under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	134.3	135.0	134.0	123.0	119.0	**129.1**	112.7	111.7	110.3	109.2	104.7	**109.7**	92.0	92.3	89.0	88.0	87.0	**89.7**
C-306	138.0	135.3	135.0	124.0	120.3	**130.5**	114.3	112.3	114.0	112.3	111.7	**112.9**	91.7	91.0	88.3	87.7	86.3	**89.0**
DHTW-60	138.7	136.9	135.3	127.6	125.7	**132.8**	118.8	116.0	116.0	115.0	114.7	**116.1**	102.0	100.3	96.7	92.3	92.0	**96.7**
HD-2967	138.7	137.3	136.0	129.4	126.8	**133.6**	118.1	115.9	115.6	114.7	114.6	**115.8**	100.0	99.3	95.7	91.7	91.3	**95.6**
HTW-11	137.7	134.0	132.3	121.7	120.0	**129.1**	116.3	114.0	114.1	114.7	113.3	**114.5**	99.3	97.2	94.7	90.7	90.3	**94.4**
KUNDAN	138.7	136.3	135.7	125.0	125.0	**132.1**	114.0	113.3	112.2	111.0	109.3	**112.0**	93.7	93.3	90.7	89.3	88.0	**91.0**
WH-730	137.0	135.0	133.7	124.0	121.0	**130.1**	113.0	112.3	111.3	112.0	110.0	**111.7**	95.3	94.0	92.0	89.7	90.3	**92.3**
WH-1105	140.0	137.3	137.0	130.0	128.7	**134.6**	117.7	116.3	115.6	114.7	113.6	**115.6**	92.7	92.7	89.3	89.3	87.7	**90.3**
Mean (D)	**137.9**	**135.9**	**134.9**	**125.6**	**123.3**	**131.5**	**115.6**	**114.0**	**113.6**	**113.0**	**111.5**	**113.5**	**95.8**	**95.0**	**92.1**	**89.8**	**89.1**	**92.4**
CD at 5%	**D= 2.21, G=1.27, DxG=NS**						**D= 1.83, G=2.32, DxG= NS**						**D= 1.57, G=2.00, DxG= 2.56**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

4.1.2 Days to physiological maturity

Data presented in Table 3 showed a signification reduction in days to physiological maturity in all genotypes along with time of drought application and delayed sowing condition. Drought application reduced the days to physiological maturity in timely, late and very late sown conditions and maximum days to physiological maturity were found in control (irrigated) condition (137.9) under timely sown condition and minimum days to physiological maturity were observed in compete drought stress (89.1) under very late sown condition.

Average days to physiological maturity for different drought stress condition ranged from 123.3 to 137.9 (timely sown), 111.5 to 115.6 (late sown) and 89.1 to 95.8 (very late sown). The drought situation of D40+D65 and complete drought resulted significant reduction in days to physiological maturity (125.6 and 123.3) respectively, under timely sown condition and under late sown condition significant reduction for days to physiological maturity was observed in complete drought (111.5) condition, however under very late sown condition significant reduction for days to physiological maturity was observed in D40+D65 (89.8) and complete drought (89.1) condition.

Days to physiological maturity showed significant difference in all genotypes and different drought stress condition whereas, no significant difference was observed among drought and genotypes interaction under timely sown and late sown condition but very late sown condition showed significant interaction effect for drought and genotypes.

Average days to physiological maturity for genotypes ranged from 129.1 to 134.6 (timely sown), 109.7 to 116.1 (late sown) and 89.0 to 96.7 (very late sown). Genotype WH-1105 (134.6) followed by HD-2967 (133.6) had maximum days to physiological maturity under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (116.1) and HD-2967 (115.8) followed by WH-1105 (115.6) had maximum day to physiological maturity under late sown condition and genotypes DHTW-60 (96.7) and HD-2967 (95.6) followed by HTW-11 (94.4) under very late sown condition. Genotype AKAW-3717 showed minimum average days to physiological maturity among all genotypes under all drought and delayed sowing conditions.

4.2 PHYSIOLOGICAL PARAMETERS

The physiological parameters were recorded on flag leaf at anthesis and 15 days after anthesis during both crop seasons and pooled mean data are presented.

4.2.1 Osmotic potential (-MPa)

Leaf osmotic potential was slightly influenced by delayed sowing but strongly affected by imposition of drought. Combined effect of heat and drought stress decreased osmotic potential at anthesis and 15 days after anthesis but the reduction was found more at 15 days after anthesis.

Table 4 showed results of osmotic potential at anthesis and 15 days after anthesis under different drought condition ins timely sown condition. Average osmotic potential for different drought stress condition ranged from -1.31 to -1.75 MPa (anthesis) and -1.37 to -1.91 MPa (at

15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on osmotic potential at anthesis (-1.68 and -1.75 MPa) and (-1.89 and -1.91 MPa) at 15 days after anthesis respectively, under timely sown condition. Osmotic potential showed significant difference in all genotypes and different drought condition. Significant difference was observed among drought and genotypes interaction under timely sown. Average osmotic potential for genotypes ranged from -1.18 to -1.91 MPa (anthesis) and -1.28 to -2.03 MPa (at 15 days after anthesis). Genotype WH-1105 (-1.91 and -2.03 MPa) followed by HD-2967 (-1.78 and -1.92 MPa) had maximum osmotic potential at anthesis and 15 days after anthesis respectively. Genotypes KUNDAN and AKAW-3717 showed minimum osmotic potential value (less negative) among all genotypes in all drought conditions at anthesis and 15 days after anthesis respectively, under timely sown conditions.

Table 5 showed average osmotic potential for different drought stress condition varied between -1.50 to -1.92 MPa (anthesis) and -1.54 to -2.24 MPa (15 days after anthesis) under late sown condition. At anthesis drought condition of D65, D40+D65 and complete drought showed significant reduction on osmotic potential (-1.74, -1.82 and -1.92 MPa) respectively, and D40+D65 and complete drought showed significant reduction at 15 days after anthesis (-2.13 and -2.24 MPa) respectively, under timely sown condition. Osmotic potential showed significant difference in all genotypes and different drought condition. Significant difference was observed among drought and genotypes interaction under late sown condition. Average osmotic potential for genotypes ranged from -1.41 to -2.05 MPa (anthesis) and -1.60 to -2.32 MPa (15 days after anthesis). Genotype DHTW (-2.05 and -2.32 MPa) and HD-2967 (-1.96 to -2.18 MPa) followed by HTW-11 (-1.88 and -2.01 MPa) had maximum osmotic potential at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed minimum average osmotic potential value (less negative) among all genotypes in all drought conditions at anthesis and 15 days after anthesis respectively, under late sown conditions.

Result presented in Table 6 showed osmotic potential at anthesis and 15 days after anthesis under very late sown condition. Average osmotic potential for different drought stress condition ranged from -1.55 to -2.13 MPa (anthesis) and -1.71 to -2.51 MPa (15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on osmotic potential at anthesis (-1.99 and -2.13 MPa) and (-2.19 and -2.51 MPa) 15 days after anthesis respectively, under timely sown condition. Under very late sown condition osmotic potential showed significant difference in all genotypes and different drought condition. Significant interaction effects were observed between drought and genotypes interaction. Average osmotic potential for genotypes ranged from -1.50 to -2.25 MPa (anthesis) and -1.70 to -2.62 MPa (at 15 days after anthesis). Genotype DHTW-60 (-2.25 and -2.62 MPa) followed by HD-2967 (-2.16 and -2.30 MPa) had maximum osmotic potential at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed minimum average osmotic potential value (less negative) among all genotypes in all drought conditions at anthesis and 15 days after anthesis respectively, under very late sown conditions.

Table 4: Response of wheat genotypes to drought and high temperature for osmotic potential (-MPa) at anthesis and 15 days after anthesis under timely sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	1.10	1.14	1.12	1.43	1.41	**1.24**	1.12	1.30	1.12	1.45	1.40	**1.28**
C-306	1.15	1.24	1.12	1.60	1.67	**1.36**	1.26	1.42	1.30	1.82	1.84	**1.53**
DHTW-60	1.51	1.55	1.49	1.93	2.01	**1.70**	1.57	1.69	1.57	2.12	2.15	**1.82**
HD-2967	1.61	1.63	1.60	1.87	2.18	**1.78**	1.67	1.73	1.69	2.24	2.27	**1.92**
HTW-11	1.12	1.13	1.28	1.49	1.51	**1.31**	1.19	1.27	1.24	1.73	1.69	**1.42**
KUNDAN	1.11	1.07	1.08	1.31	1.32	**1.18**	1.14	1.36	1.20	1.55	1.49	**1.35**
WH-730	1.23	1.26	1.15	1.53	1.63	**1.36**	1.28	1.56	1.34	1.87	1.93	**1.60**
WH-1105	1.66	1.68	1.67	2.27	2.26	**1.91**	1.74	1.86	1.73	2.35	2.47	**2.03**
Mean (D)	**1.31**	**1.34**	**1.31**	**1.68**	**1.75**	**1.48**	**1.37**	**1.52**	**1.40**	**1.89**	**1.91**	**1.62**
CD at 5%	**D = 0.02, G= 0.02, DxG= 0.05**						**D = 0.03, G= 0.03, DxG=0.073**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 5: Response of wheat genotypes to drought and high temperature for osmotic potential (-MPa) at anthesis and 15 days after anthesis under late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	1.26	1.29	1.45	1.48	1.55	**1.41**	1.25	1.52	1.43	1.86	1.92	**1.60**
C-306	1.36	1.37	1.67	1.79	1.88	**1.61**	1.35	1.69	1.50	1.87	1.85	**1.65**
DHTW-60	1.76	1.80	2.22	2.23	2.26	**2.05**	1.92	2.26	2.15	2.48	2.79	**2.32**
HD-2967	1.71	1.70	2.01	2.13	2.24	**1.96**	1.84	2.12	2.01	2.44	2.49	**2.18**
HTW-11	1.60	1.62	1.94	2.04	2.20	**1.88**	1.68	1.86	1.75	2.29	2.47	**2.01**
KUNDAN	1.41	1.47	1.55	1.71	1.86	**1.60**	1.42	1.97	1.69	2.01	2.12	**1.84**
WH-1105	1.64	1.61	1.68	1.69	1.72	**1.67**	1.55	1.85	1.64	2.02	2.15	**1.84**
WH-730	1.29	1.30	1.37	1.50	1.65	**1.42**	1.31	1.69	1.53	1.80	1.82	**1.63**
Mean (D)	**1.50**	**1.52**	**1.74**	**1.82**	**1.92**	**1.70**	**1.54**	**1.92**	**1.75**	**2.13**	**2.24**	**1.92**
CD at 5%	**D = 0.03, G = 0.04, DxG=0.08**						**D = 0.03, G= 0.04, DxG=0.08**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 6: Response of wheat genotypes to drought and high temperature for osmotic potential (-MPa) at anthesis and 15 days after anthesis under very late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	1.21	1.54	1.47	1.54	1.75	**1.50**	1.39	1.68	1.41	1.92	2.10	**1.70**
C-306	1.28	1.40	1.43	1.69	1.73	**1.51**	1.43	1.69	1.68	1.81	2.01	**1.72**
DHTW-60	1.87	2.02	2.16	2.44	2.76	**2.25**	2.10	2.41	2.12	2.88	3.61	**2.62**
HD-2967	1.81	1.98	2.22	2.34	2.47	**2.16**	2.01	2.24	1.96	2.44	2.86	**2.30**
HTW-11	1.72	1.91	1.97	2.29	2.47	**2.07**	1.84	2.11	1.77	2.29	2.69	**2.14**
KUNDAN	1.53	1.66	1.73	1.97	2.01	**1.78**	1.56	1.86	1.69	2.04	2.44	**1.92**
WH-1105	1.54	1.62	1.76	2.01	2.09	**1.80**	1.80	2.10	1.77	2.12	2.29	**2.02**
WH-730	1.47	1.38	1.39	1.62	1.73	**1.52**	1.55	1.64	1.50	2.00	2.04	**1.75**
Mean (D)	**1.55**	**1.69**	**1.77**	**1.99**	**2.13**	**1.82**	**1.71**	**1.97**	**1.74**	**2.19**	**2.51**	**2.02**
CD at 5%	**D = 0.03, G= 0.03, DxG=0.07**						**D = 0.03, G= 0.04, DxG=0.08**					

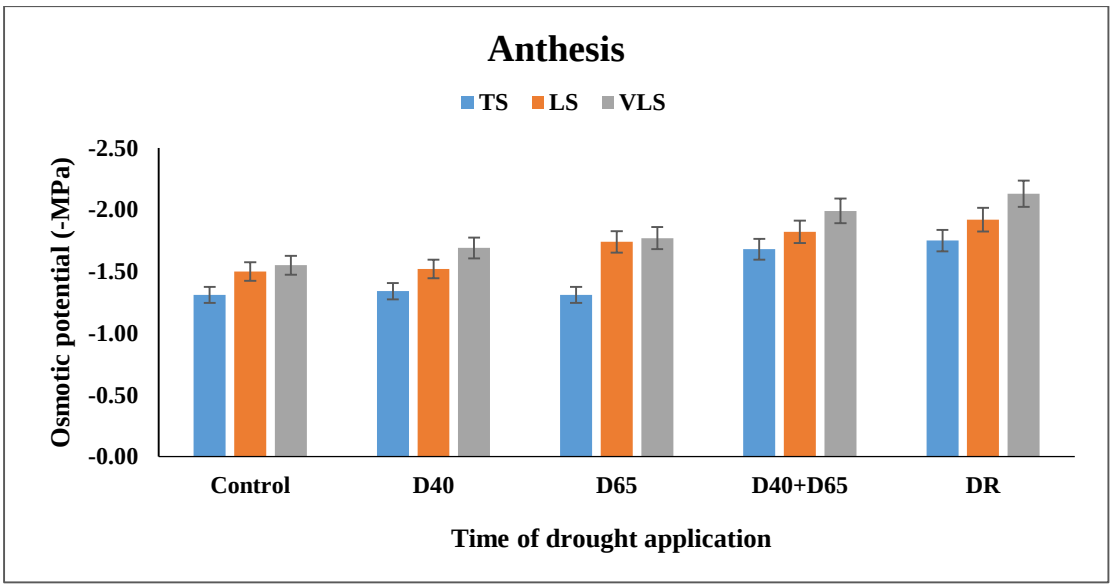
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 7: Mean sum of square of wheat genotypes for osmotic potential in response to drought and high temperature at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Osmotic potential (-MPa)	
		Anthesis	15 DAA
Replication	2	0.049**	0.070**
Genotype (G)	7	3.238**	3.699**
Drought Treatment (D)	4	5.388**	8.360**
GxD	28	0.036**	0.064**
Sowing Time (S)	2	0.413**	0.990**
GxS	14	0.004**	0.013**
DxS	8	0.017**	0.065**
GxDxS	56	0.003**	0.012**
Error	238	0.001	0.001

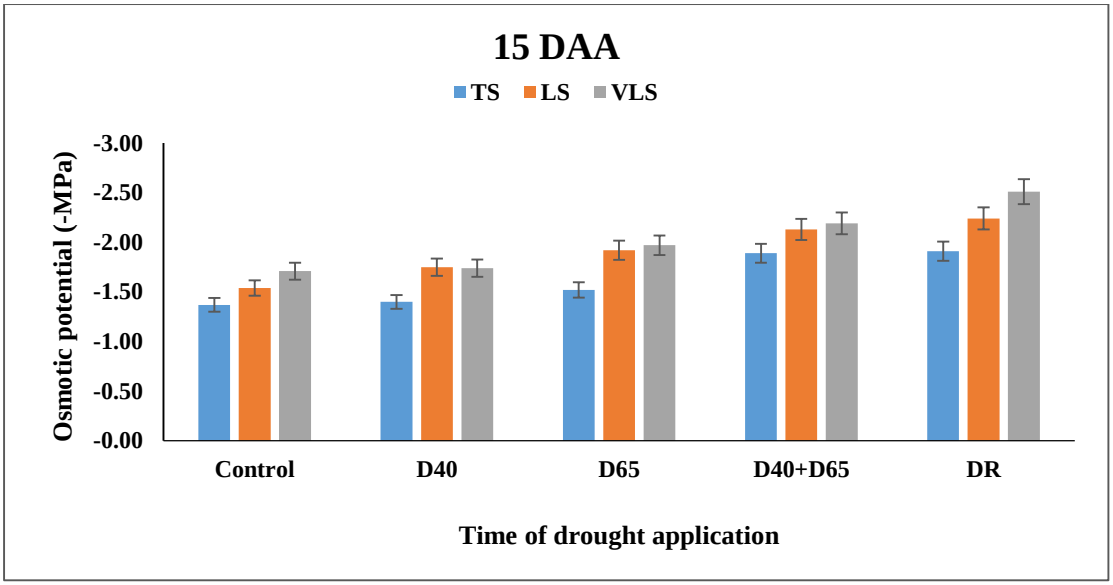
**** Significant at 1% of significance**

The mean sum of square for osmotic potential at anthesis and 15 days after anthesis sown in Table 7 indicated significant difference due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was also found. This indicated that genotypes differed in their response to drought condition and sowing time of the traits under study.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 3: Response of wheat genotypes to drought and high temperature for osmotic potential at anthesis under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 4: Response of wheat genotypes to drought and high temperature for osmotic potential at 15 days after anthesis under timely, late and very late sown conditions

Graphical representation of osmotic potential under different drought sowing condition at anthesis and 15 days after anthesis is sown in Fig. 3 and 4. Variation in osmotic potential at D40, D40+D65 and complete drought was found at anthesis with different sowing conditions but at 15 days after anthesis significant difference in osmotic potential was obtained under complete drought condition.

4.2.2 Water potential (-MPa)

Result of different drought condition presented in Table 8 showed reduction in water potential at anthesis and 15 days after anthesis under timely sown condition. Average water potential for different drought stress condition varied between -1.63 to -1.75 MPa (anthesis) and -1.68 to -1.91 MPa (at 15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction (more negative) on water potential at anthesis (-1.73 and -1.75 MPa) and at 15 days after anthesis (-1.86 and -1.91 MPa) respectively, under timely sown condition. Water potential showed significant difference in all genotypes and different drought condition. No significant difference was observed among drought and genotypes interaction at anthesis but 15 days after anthesis showed significant interaction effect for drought and genotypes.

Average water potential for genotypes ranged from -1.27 to -2.06 MPa (anthesis) and -1.40 to -2.21 MPa (at 15 days after anthesis). Genotype WH-1105 (-1.27 and -1.40 MPa) followed by HD-2967 (-1.43 and -1.49 MPa) had maximum water potential at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in water

potential among all genotypes in all drought conditions at anthesis and 15 days after anthesis under timely sown conditions.

Table 9 showed reduction in water potential at anthesis and 15 days after anthesis under different drought situation of late sown condition. Average water potential for different drought stress condition ranged from -1.69 to -1.84 MPa (anthesis) and -1.75 to -1.97 MPa (at 15 days after anthesis). Drought condition of D65, D40+D65 and complete drought showed significant reduction (more negative) on water potential at anthesis (-1.74. -1.79 and -1.84 MPa) and at 15 days after anthesis (-1.84, 1.91 and -1.97 MPa) respectively, under late sown condition. All genotypes and different drought condition showed significant difference in water potential. No significant difference was observed for interaction effect of drought and genotypes at anthesis but 15 days after anthesis showed significant interaction effect for drought and genotypes.

Average water potential for genotypes ranged from -1.33 to -2.15 MPa (anthesis) and -1.45 to -2.28 MPa (at 15 days after anthesis). Genotype DHTW-60 (-1.33 and -1.40 MPa), HD-2967 (-1.49 and -1.52 MPa) followed by WH-1105 (-1.62 and -1.66 MPa) had maximum water potential at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in water potential among all genotypes in all drought conditions at anthesis and 15 days after anthesis under late sown conditions.

Result presented in Table 10 showed reduction in water potential at anthesis and 15 days after anthesis under very late sown condition. Average water potential for different drought stress condition ranged from -1.80 to -1.98 MPa (anthesis) and -1.98 to -2.42 MPa (at 15 days after anthesis). Drought condition of D65, D40+D65 and complete drought showed significant reduction (more negative) on water potential at anthesis (-1.87. -1.93 and -1.98 MPa) and at 15 days after anthesis (-2.35, -2.39 and -2.42 MPa) respectively, under very late sown condition. All genotypes and different drought condition showed significant difference in water potential. Significant difference was observed for interaction effect of drought and genotypes at anthesis and 15 days after anthesis.

Average water potential for genotypes ranged from -1.45 to -2.32 MPa (anthesis) and -1.60 to -3.16 MPa (at 15 days after anthesis). Genotype DHTW-60 (-1.45 and -1.60 MPa), HD-2967 (-1.62 and -1.75 MPa) followed by HTW-11 (-1.75 to -1.79 MPa) had maximum water potential at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in water potential among all genotypes in all drought conditions at anthesis and 15 days after anthesis under very late sown conditions.

Table 8: Response of wheat genotypes to drought and high temperature for water potential (-MPa) at anthesis and 15 days after anthesis under timely sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	2.00	2.00	2.05	2.11	2.15	**2.06**	2.07	2.28	2.12	2.26	2.30	**2.21**
C-306	1.65	1.64	1.70	1.78	1.80	**1.71**	1.71	1.90	1.86	1.93	1.95	**1.87**
DHTW-60	1.50	1.52	1.58	1.63	1.65	**1.58**	1.56	1.68	1.60	1.70	1.77	**1.66**
HD-2967	1.40	1.42	1.43	1.45	1.45	**1.43**	1.41	1.43	1.49	1.52	1.58	**1.49**
HTW-11	1.75	1.75	1.78	1.84	1.85	**1.79**	1.78	1.90	1.87	1.97	2.00	**1.90**
KUNDAN	1.60	1.62	1.67	1.70	1.74	**1.67**	1.67	1.80	1.78	1.85	1.90	**1.80**
WH-730	1.94	1.95	2.00	2.02	2.02	**1.99**	1.97	2.17	2.08	2.20	2.25	**2.13**
WH-1105	1.20	1.24	1.29	1.31	1.32	**1.27**	1.26	1.47	1.29	1.49	1.50	**1.40**
Mean (D)	**1.63**	**1.64**	**1.69**	**1.73**	**1.75**	**1.69**	**1.68**	**1.83**	**1.76**	**1.86**	**1.91**	**1.81**
CD at 5%	**D = 0.03, D= 0.03, DxG= NS**						**D = 0.02, G = 0.03, DxG=0.07**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 9: Response of wheat genotypes to drought and high temperature for water potential (-MPa) at anthesis and 15 days after anthesis under late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	2.05	2.12	2.18	2.20	2.23	**2.15**	2.24	2.25	2.29	2.30	2.30	**2.28**
C-306	1.79	1.81	1.89	1.91	1.92	**1.86**	1.82	1.87	1.94	2.07	2.11	**1.96**
DHTW-60	1.27	1.28	1.30	1.38	1.42	**1.33**	1.33	1.40	1.44	1.52	1.58	**1.45**
HD-2967	1.46	1.48	1.44	1.50	1.58	**1.49**	1.47	1.48	1.50	1.54	1.59	**1.52**
HTW-11	1.66	1.69	1.74	1.79	1.87	**1.75**	1.69	1.74	1.81	1.97	2.00	**1.84**
KUNDAN	1.70	1.69	1.72	1.75	1.85	**1.74**	1.76	1.78	1.87	2.00	2.07	**1.90**
WH-730	1.98	1.99	2.01	2.16	2.21	**2.07**	2.08	2.12	2.19	2.22	2.35	**2.19**
WH-1105	1.58	1.59	1.62	1.63	1.67	**1.62**	1.60	1.62	1.65	1.67	1.79	**1.66**
Mean (D)	**1.69**	**1.71**	**1.74**	**1.79**	**1.84**	**1.75**	**1.75**	**1.78**	**1.84**	**1.91**	**1.97**	**1.85**
CD at 5%	**D = 0.03, G= 0.04, DxG= NS**						**D = 0.03, G = 0.03, DxG=0.07**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 10: Response of wheat genotypes to drought and high temperature for water potential (-MPa) at anthesis and 15 days after anthesis under very late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	2.17	2.29	2.30	2.36	2.47	**2.32**	2.65	2.96	3.35	3.40	3.44	**3.16**
C-306	2.12	2.16	2.27	2.32	2.39	**2.25**	2.43	2.83	3.18	3.20	3.26	**2.98**
DHTW-60	1.36	1.38	1.42	1.54	1.52	**1.45**	1.51	1.61	1.62	1.63	1.65	**1.60**
HD-2967	1.53	1.57	1.62	1.65	1.74	**1.62**	1.62	1.79	1.77	1.77	1.80	**1.75**
HTW-11	1.73	1.74	1.75	1.76	1.76	**1.75**	1.73	1.74	1.81	1.84	1.86	**1.79**
KUNDAN	1.85	1.89	1.90	1.92	1.99	**1.91**	1.99	2.01	2.06	2.22	2.25	**2.11**
WH-730	1.86	1.89	1.92	1.99	2.01	**1.93**	2.04	2.41	2.87	2.90	2.93	**2.63**
WH-1105	1.77	1.73	1.80	1.88	1.93	**1.82**	1.90	2.02	2.18	2.13	2.13	**2.07**
Mean (T)	**1.80**	**1.83**	**1.87**	**1.93**	**1.98**	**1.88**	**1.98**	**2.17**	**2.35**	**2.39**	**2.42**	**2.26**
CD at 5%	**D = 0.07, G= 0.04, DxG=0.08**						**D= 0.41, G= 0.05, DxG=0.11**					

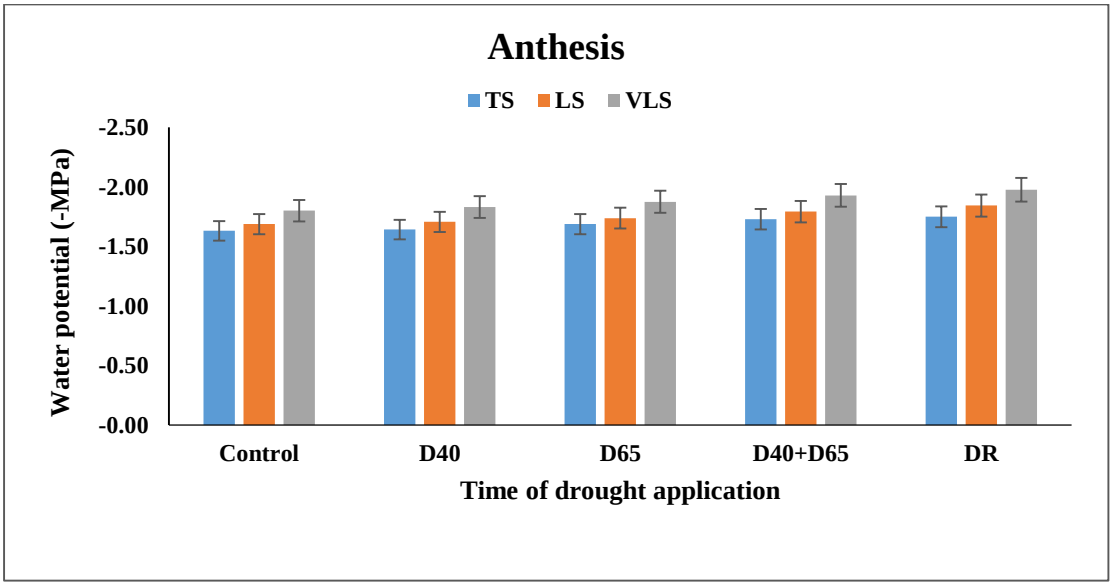
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 11: Mean sum of square of wheat genotypes for water potential in response to drought and high temperature at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Water potential (-MPa)	
		Anthesis	15 DAA
Replication	2	0.0135**	0.028**
Genotype (G)	7	3.507**	6.701**
Drought Treatment (D)	4	0.978**	5.113**
Int GxD	28	0.006**	0.297**
Sowing Time (S)	2	0.105**	0.342**
GxS	14	0.001**	0.014**
DxS	8	0.005**	0.033**
GxDxS	56	0.001**	0.008**
Error	238	<0.0001	<0.0001

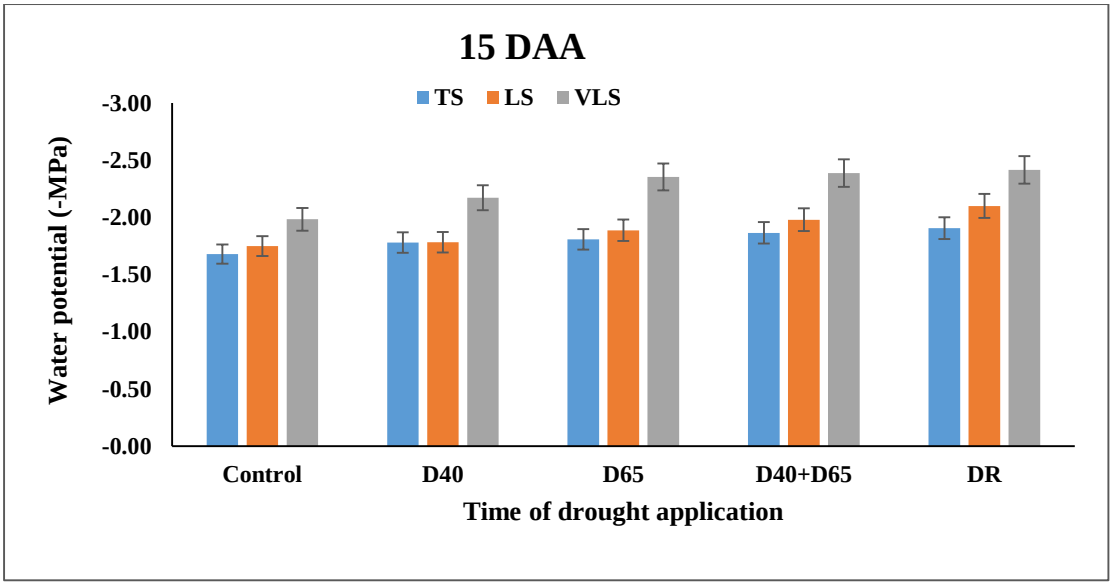
**** Significant at 1% of significance**

Table 11 showed the mean sum of square for water potential at anthesis and 15 days after anthesis. These result indicated significant difference due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for water potential.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 5: Response of wheat genotypes to drought and high temperature for water potential at anthesis under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 6: Response of wheat genotypes to drought and high temperature for water potential at 15 days after anthesis under timely, late and very late sown conditions

Fig 5 and 6 showed graphical representation of water potential under different drought sowing condition at anthesis and 15 days after anthesis. Variation in water potential at D40, D65, D40+D65 and complete drought was found at anthesis with different sowing conditions but at 15 days after anthesis significant difference in water potential was obtained under D65, D40+D65 and complete drought condition.

4.2.3 Relative Water content (%)

Relative water content (RWC) in different drought condition presented in Table 12, 13 and 14 at anthesis and 15 days after anthesis under timely, late and very late sown condition respectively. Pooled mean data showed maximum reduction in relative water content at 15 days after anthesis as compare to anthesis.

Table 12 showed reduction in flag leaf relative water content at anthesis and 15 days after anthesis under different drought situation in timely sown condition. Average relative water content for different drought stress condition ranged from 66.1 to 85.3 % (anthesis) and 63.3 to 82.5 % (at 15 days after anthesis). Drought situation of D65, D40+D65 and complete drought showed significant reduction on relative water content at anthesis (73.8, 69.4 and 66.1 %) and at 15 days after anthesis (69.2, 63.0 and 60.3 %) respectively, under timely sown condition. Relative water content showed significant difference in all genotypes and different drought condition. Interaction between drought and genotypes sowed significant difference at anthesis and 15 days after anthesis.

Average relative water content for genotypes varied between 68.9 to 80.5 % (anthesis) and 63.1 to 78.1 % (at 15 days after anthesis). Genotype WH-1105 (80.5 and 78.1 %) and HD-

2967 (79.4 and 75.5 %) followed by DHTW-60 (78.2 and 73.8 %) had maximum relative water content at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 found lowest in relative water content among all genotypes studies in all drought conditions at anthesis and 15 days after anthesis under timely sown conditions.

Relative water content showed significant reduction at anthesis and 15 days after anthesis under late sown condition in Table 13. Average relative water content for different drought stress condition ranged from 56.8 to 81.4 % (anthesis) and 54.1 to 75.6 % (at 15 days after anthesis). Drought situation of D40+D65 and complete drought showed significant reduction in relative water content at anthesis (65.6 and 56.8 %) and at 15 days after anthesis (58.5 and 54.1 %) respectively, under late sown condition. All genotypes and different drought condition showed significant difference in relative water content. Significant difference observed for interaction effect of drought and genotypes at anthesis and 15 days after anthesis.

Average relative water content for genotypes ranged from 61.5 to 76.3 % (anthesis) and 59.4 to 71.0 % (at 15 days after anthesis). Genotype DHTW-60 (76.3 and 71.0 %), HD-2967 (75.4 and 70.5 %) followed by WH-1105 (74.3 and 68.3 %) had maximum relative water content at anthesis and 15 days after anthesis respectively. Reduction in relative water content among all genotypes was more in genotype AKAW-3717 under all drought conditions at anthesis and 15 days after anthesis under timely sown conditions.

Result presented in Table 14 showed reduction in relative water content at anthesis and 15 days after anthesis under very late sown condition. Average relative water content for different drought stress condition fluctuated between 59.5 to 77.8 % (anthesis) and 55.9 to 73.3 % (at 15 days after anthesis). Drought situation of D40+D65 and complete drought showed significant reduction on relative water content at anthesis (62.9 and 59.5 %) respectively, but at 15 days after anthesis drought condition D65, D40+D65 and complete drought showed significant reduction on relative water content (61.9, 60.0 and 55.9 %) respectively, under very late sown condition. All genotypes and different drought condition showed significant difference in relative water content. Significant difference observed for interaction between drought and genotypes at anthesis and 15 days after anthesis.

Average relative water content for genotypes ranged from 62.2 to 75.4 % (anthesis) and 58.4 to 71.4 % (at 15 days after anthesis). Genotype DHTW-60 (75.4 and 71.4 %), HD-2967 (70.2 and 69.8 %) followed by HTW-11 (71.8 and 67.0 %) had maximum relative water content at anthesis and 15 days after anthesis respectively. Reduction in relative water content among all genotypes was more in genotype AKAW-3717 in all drought conditions at anthesis and 15 days after anthesis under timely sown conditions.

Table 12: Response of wheat genotypes to drought and high temperature for relative water content (%) at anthesis and 15 days after anthesis under timely sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	82.3	78.0	66.0	60.3	57.9	**68.9**	74.1	68.1	63.0	58.4	51.9	**63.1**
C-306	85.0	84.3	74.7	66.9	61.1	**74.4**	80.5	69.4	64.6	55.0	55.7	**65.0**
DHTW-60	87.9	82.9	76.7	73.4	70.3	**78.2**	83.7	80.2	72.7	67.5	65.0	**73.8**
HD-2967	88.1	84.9	77.1	74.8	72.3	**79.4**	87.6	81.3	74.7	67.8	66.1	**75.5**
HTW-11	82.8	80.8	73.3	64.9	61.3	**72.6**	81.9	76.7	69.9	63.4	59.3	**70.2**
KUNDAN	85.7	84.3	75.9	72.2	69.3	**77.5**	83.0	77.0	71.6	66.3	62.6	**72.1**
WH-730	82.7	79.3	68.5	65.4	63.2	**71.8**	76.5	69.1	61.1	54.9	52.3	**62.8**
WH-1105	88.2	85.4	78.3	76.9	73.8	**80.5**	93.0	82.0	75.8	70.6	69.2	**78.1**
Mean (D)	**85.3**	**82.5**	**73.8**	**69.4**	**66.1**	**75.4**	**82.5**	**75.5**	**69.2**	**63.0**	**60.3**	**70.1**
CD at 5%	**D = 2.01, G = 2.27, DxG= 3.84**						**D = 1.67, G = 2.85, DxG= 2.90**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 13: Response of wheat genotypes to drought and high temperature for relative water content (%) at anthesis and 15 days after anthesis under late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	74.0	64.9	62.6	54.3	51.8	**61.5**	69.9	63.6	60.4	53.0	50.3	**59.4**
C-306	79.5	71.3	68.1	63.3	54.3	**67.3**	75.5	72.5	68.3	58.0	53.6	**65.6**
DHTW-60	86.5	83.3	76.0	73.6	62.0	**76.3**	80.6	77.7	74.0	63.3	59.7	**71.0**
HD-2967	85.9	83.0	75.1	71.1	62.5	**75.5**	79.3	76.8	74.0	64.0	58.4	**70.5**
HTW-11	81.1	80.3	72.4	69.3	58.3	**72.3**	76.9	72.9	70.9	58.4	54.3	**66.7**
KUNDAN	80.9	78.7	71.0	64.2	56.6	**70.3**	73.3	68.6	64.3	54.6	51.3	**62.4**
WH-730	78.8	69.4	63.9	58.6	49.5	**64.1**	70.6	66.3	63.7	56.8	50.4	**61.5**
WH-1105	84.8	82.3	74.3	70.8	59.5	**74.3**	79.2	76.0	71.5	59.7	55.1	**68.3**
Mean (D)	**81.4**	**76.6**	**70.4**	**65.6**	**56.8**	**70.2**	**75.6**	**71.8**	**68.4**	**58.5**	**54.1**	**65.7**
CD at 5%	**D = 1.99, G = 2.26, DxG= 3.79**						**D = 1.56, G = 1.71, DxG= 2.59**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 14: Response of wheat genotypes to drought and high temperature for relative water content (%) at anthesis and 15 days after anthesis under very late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	70.5	67.3	59.0	58.2	56.2	**62.2**	68.8	61.4	57.1	55.1	51.6	**58.8**
C-306	71.9	62.6	65.2	58.2	56.2	**62.8**	68.4	60.1	55.1	56.6	51.9	**58.4**
DHTW-60	84.4	78.2	80.8	68.6	64.9	**75.4**	80.3	76.2	70.7	68.0	62.0	**71.4**
HD-2967	82.9	73.3	69.2	64.8	60.7	**70.2**	78.6	72.0	70.2	66.5	61.6	**69.8**
HTW-11	81.2	73.7	74.3	67.9	62.1	**71.8**	75.9	71.5	66.0	63.6	58.0	**67.0**
KUNDAN	76.5	68.9	66.2	60.8	57.9	**66.1**	71.3	66.4	58.9	55.7	52.6	**61.0**
WH-730	74.7	68.2	65.8	60.4	56.5	**65.1**	69.4	66.1	56.2	53.5	50.7	**59.2**
WH-1105	80.5	69.5	68.6	64.1	61.1	**68.8**	73.6	65.8	60.7	61.3	58.6	**64.0**
Mean (D)	**77.8**	**70.2**	**68.6**	**62.9**	**59.5**	**67.8**	**73.3**	**67.4**	**61.9**	**60.0**	**55.9**	**63.7**
CD at 5%	**D = 1.64, G = 1.81, DxG= 2.82**						**D = 1.44, G= 1.56, DxG= 2.25**					

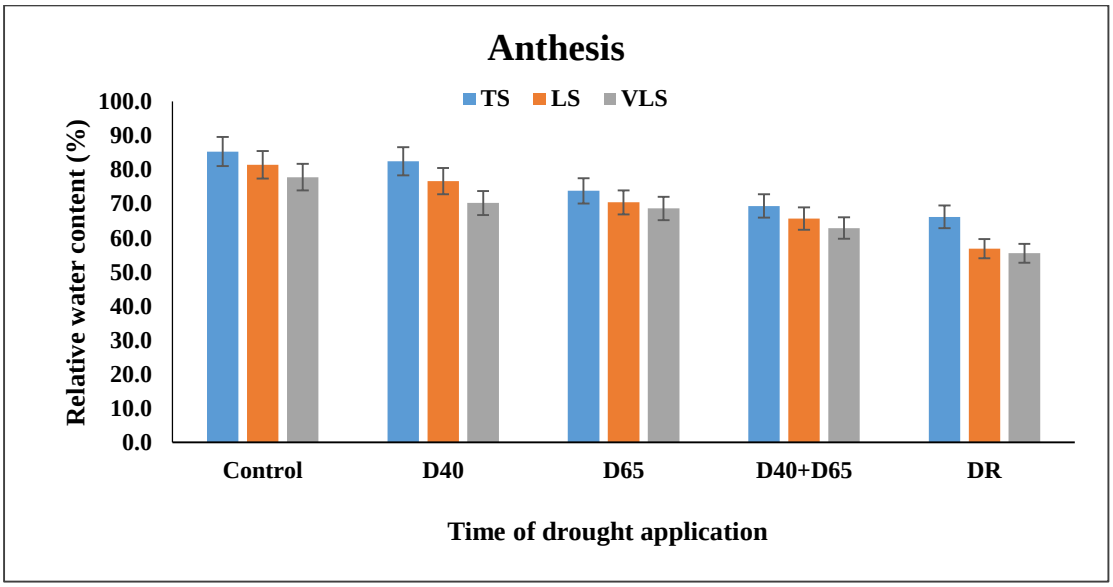
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 15: Mean sum of square of wheat genotypes for relative water content in response to drought and high temperature at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Relative Water Content (%)	
		Anthesis	15 DAA
Replication	2	58.078**	68.615**
Genotype (G)	7	970.594**	1096.701**
Drought Treatment (D)	4	6023.438**	5657.602**
GxD	28	12.073**	7.912**
Sowing Time (S)	2	563.142**	584.852**
GxS	14	1.343**	1.566**
DxS	8	12.093**	26.275**
GxDxS	56	2.16**	2.786**
Error	238	0.336	0.418

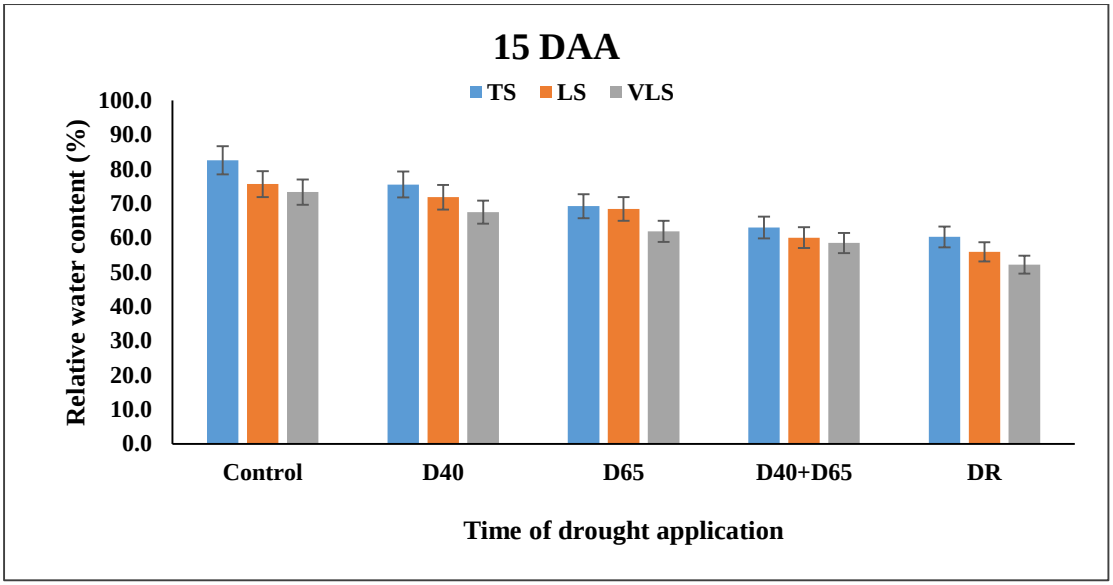
**** Significant at 1% of significance**

Table 15 showed the mean sum of square for relative water content at anthesis and 15 days after anthesis. These result indicated that there is genetic difference in genotypes under studies with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for relative water content.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 7: Response of wheat genotypes to drought and high temperature for relative water content at anthesis under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 8: Response of wheat genotypes to drought and high temperature for relative water content at 15 days after anthesis under timely, late and very late sown conditions

Fig 5 and 6 showed relative water content under different drought sowing condition at anthesis and 15 days after anthesis in graphical representation. Divergence in RWC at D40, D65 and D40+D65 was found at anthesis with different sowing conditions but at 15 days after anthesis significant difference in relative water content was obtained under D40, D40+D65 and complete drought condition.

4.2.4 Chlorophyll fluorescence (Fv/Fm)

Decreases in chlorophyll fluorescence recorded in different drought treatments and delayed sowing as compare to control (irrigated) at anthesis and 15 days after anthesis under timely, late and very late sowing condition.

Table 16 showed results of chlorophyll fluorescence at anthesis and 15 days after anthesis under timely sown condition. Average chlorophyll fluorescence for different drought stress condition ranged from 0.682 to 0.853 (anthesis) and 0.587 to 0.831 (at 15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on chlorophyll fluorescence at anthesis (0.754 and 0.682) and (0.730 and 0.587) at 15 days after anthesis respectively, under timely sown condition. Chlorophyll fluorescence showed significant difference in all genotypes and different drought condition. Significant difference was observed among drought and genotypes interaction under timely sown.

Average chlorophyll fluorescence for genotypes ranged from 0.754 and 0.828 (anthesis) and 0.717 and 0.794 (at 15 days after anthesis). Genotype WH-1105 (0.828 and 0.794) followed by HD-2967 (0.822 and 0.783) had maximum chlorophyll fluorescence at

anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed minimum chlorophyll fluorescence value in all drought conditions at anthesis and 15 days after anthesis respectively, among all genotypes under timely sown conditions.

Table 17 showed average chlorophyll fluorescence for different drought stress condition varied between 0.641 to 0.803 (anthesis) and 0.561 and 0.785 (15 days after anthesis) under late sown condition. At anthesis drought condition of D40+D65 and complete drought showed significant reduction on chlorophyll fluorescence at anthesis (0.721 and 0.641) and at 15 days after anthesis (0.714 and .561) respectively, under late sown condition. Chlorophyll fluorescence showed significant difference in all genotypes and different drought condition. Significant difference was observed among drought and genotypes interaction under late sown condition.

Average chlorophyll fluorescence for genotypes ranged from 0.700 to 0.786 (anthesis) and 0.687 and 0.758 (15 days after anthesis). Genotype DHTW (0.786 and 0.758) and HD-2967 (0.775 and 0.749) followed by WH-1105 (0.762 and 0.735) had maximum chlorophyll fluorescence at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 was found to have lowest in chlorophyll fluorescence among all genotypes in all drought conditions at anthesis and 15 days after anthesis respectively, under late sown conditions.

Result presented in Table 18 showed chlorophyll fluorescence at anthesis and 15 days after anthesis under very late sown condition. Average chlorophyll fluorescence for different drought stress condition ranged from 0.580 and 0.785 (anthesis) and 0.475 and 0.637 (15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on chlorophyll fluorescence at anthesis (0.662 and 0.580) and (0.546 and 0.457) at 15 days after anthesis respectively, under timely sown condition. Under very late sown condition chlorophyll fluorescence showed significant difference in all genotypes and different drought condition. Significant interaction effects were observed between drought and genotypes interaction for chlorophyll fluorescence.

Average chlorophyll fluorescence for genotypes ranged from 0.660 to 0.757 (anthesis) and 0.526 and 0.618 (at 15 days after anthesis). Genotype DHTW-60 (0.757 and 0.618) and HD-2967 (0.746 and 0.608) followed by HTW-11 (0.727 and 0.595) had maximum chlorophyll fluorescence at anthesis and 15 days after anthesis respectively. Under very late sown condition genotype AKAW-3717 had minimum chlorophyll fluorescence among all genotypes in all drought conditions at anthesis and 15 days after anthesis respectively.

Table 16: Response of wheat genotypes to drought and high temperature for chlorophyll fluorescence (Fv/Fm) at anthesis and 15 days after anthesis under timely sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	0.823	0.808	0.789	0.728	0.624	**0.754**	0.805	0.789	0.763	0.700	0.526	**0.717**
C-306	0.831	0.819	0.801	0.749	0.683	**0.777**	0.812	0.802	0.784	0.728	0.584	**0.742**
DHTW-60	0.847	0.841	0.839	0.767	0.703	**0.799**	0.841	0.834	0.815	0.742	0.620	**0.770**
HD-2967	0.911	0.863	0.849	0.773	0.713	**0.822**	0.864	0.851	0.820	0.750	0.631	**0.783**
HTW-11	0.826	0.818	0.798	0.744	0.671	**0.771**	0.810	0.796	0.777	0.718	0.545	**0.729**
KUNDAN	0.845	0.841	0.835	0.758	0.691	**0.794**	0.836	0.830	0.813	0.739	0.598	**0.763**
WH-730	0.825	0.809	0.792	0.735	0.648	**0.762**	0.808	0.792	0.770	0.705	0.537	**0.722**
WH-1105	0.919	0.873	0.852	0.777	0.720	**0.828**	0.871	0.858	0.828	0.756	0.657	**0.794**
Mean (D)	**0.853**	**0.834**	**0.819**	**0.754**	**0.682**	**0.788**	**0.831**	**0.819**	**0.796**	**0.730**	**0.587**	**0.753**
CD at 5%	**D = 0.011, G = 0.005, DxG= 0.012**						**D = 0.017, G= 0.015, DxG=0.028**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 17: Response of wheat genotypes to drought and high temperature for chlorophyll fluorescence (Fv/Fm) at anthesis and 15 days after anthesis under late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	0.764	0.756	0.746	0.700	0.532	**0.700**	0.753	0.748	0.740	0.692	0.500	**0.687**
C-306	0.787	0.781	0.772	0.713	0.641	**0.739**	0.772	0.768	0.761	0.705	0.528	**0.707**
DHTW-60	0.857	0.828	0.815	0.742	0.689	**0.786**	0.818	0.807	0.798	0.733	0.633	**0.758**
HD-2967	0.839	0.823	0.811	0.733	0.671	**0.775**	0.812	0.802	0.796	0.726	0.609	**0.749**
HTW-11	0.807	0.802	0.796	0.726	0.655	**0.757**	0.792	0.784	0.779	0.718	0.561	**0.727**
KUNDAN	0.792	0.785	0.774	0.719	0.650	**0.744**	0.777	0.771	0.763	0.712	0.545	**0.714**
WH-730	0.767	0.760	0.750	0.706	0.621	**0.721**	0.758	0.750	0.743	0.702	0.523	**0.695**
WH-1105	0.809	0.805	0.799	0.729	0.666	**0.762**	0.795	0.788	0.783	0.723	0.586	**0.735**
Mean (D)	**0.803**	**0.793**	**0.783**	**0.721**	**0.641**	**0.748**	**0.785**	**0.777**	**0.770**	**0.714**	**0.561**	**0.721**
CD at 5%	**D = 0.008, G= 0.011, DxG= 0.023**						**D = 0.006, G= 0.009, DxG=0.017**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 18: Response of wheat genotypes to drought and high temperature for chlorophyll fluorescence (Fv/Fm) at anthesis and 15 days after anthesis under very late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	0.730	0.717	0.706	0.630	0.519	**0.660**	0.578	0.569	0.561	0.504	0.420	**0.526**
C-306	0.740	0.724	0.713	0.638	0.557	**0.674**	0.608	0.596	0.586	0.530	0.456	**0.555**
DHTW-60	0.837	0.816	0.810	0.699	0.623	**0.757**	0.679	0.664	0.657	0.576	0.512	**0.618**
HD-2967	0.824	0.812	0.804	0.686	0.605	**0.746**	0.667	0.659	0.652	0.566	0.498	**0.608**
HTW-11	0.801	0.789	0.784	0.673	0.589	**0.727**	0.652	0.644	0.639	0.557	0.484	**0.595**
KUNDAN	0.775	0.768	0.754	0.651	0.591	**0.708**	0.632	0.627	0.616	0.541	0.481	**0.579**
WH-730	0.773	0.764	0.750	0.648	0.578	**0.703**	0.630	0.623	0.612	0.538	0.472	**0.575**
WH-1105	0.797	0.787	0.781	0.667	0.574	**0.721**	0.648	0.640	0.634	0.553	0.473	**0.590**
Mean (D)	**0.785**	**0.772**	**0.763**	**0.662**	**0.580**	**0.712**	**0.637**	**0.628**	**0.620**	**0.546**	**0.475**	**0.581**
CD at 5%	**D = 0.009, G= 0.011, DxG= 0.021**						**D = 0.006, G= 0.010, DxG=0.16**					

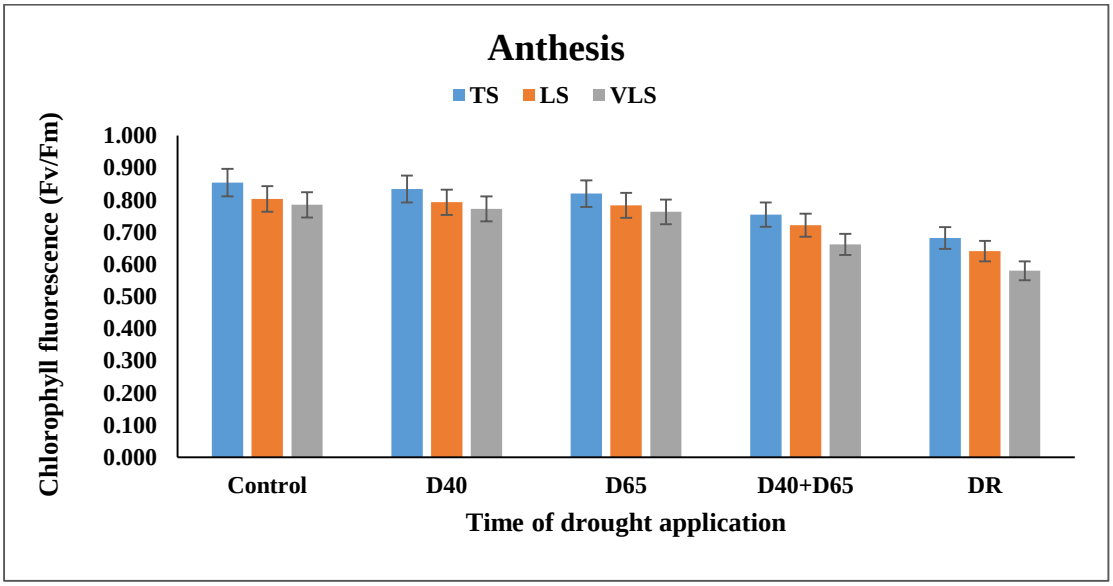
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 19: Mean sum of square of wheat genotypes for chlorophyll fluorescence in response to drought and high temperature at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Chlorophyll fluorescence (Fv/Fm)	
		Anthesis	15 DAA
Replication	2	0.005**	0.008**
Genotypes (G)	7	0.039**	0.034**
Drought Treatment (D)	4	0.474**	1.018**
GxD	28	0.001**	0.001**
Sowing Time (S)	2	0.060**	0.100**
GxS	14	0.001**	0.000**
DxS	8	0.007**	0.009**
GxDxS	56	0.001**	0.000**
Error	238	<0.0001	<0.0001

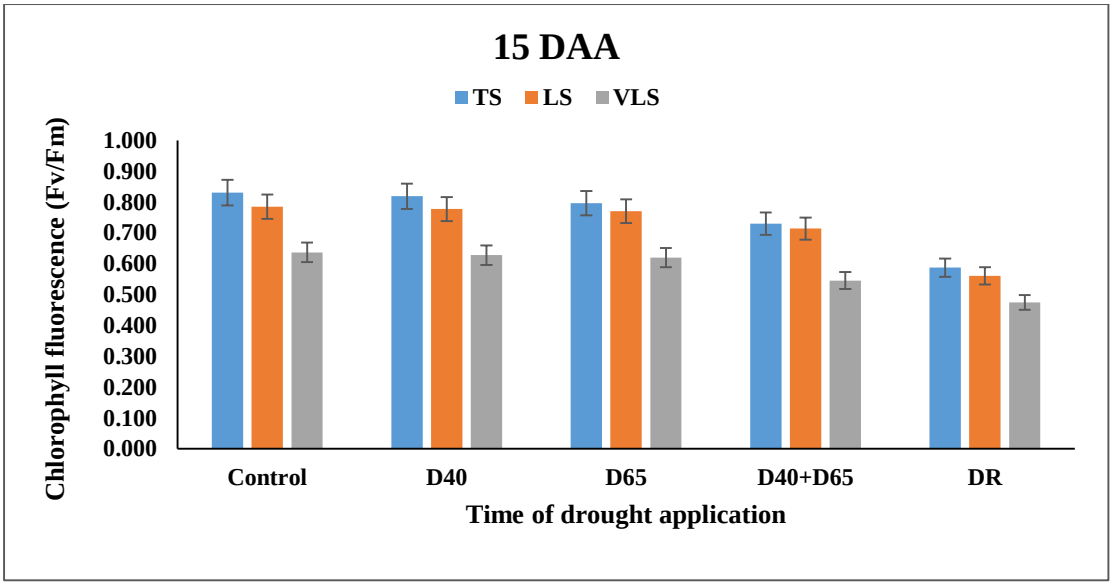
**** Significant at 1% of significance**

Mean sum of square for chlorophyll fluorescence at anthesis and 15 days after anthesis in Table 19 indicated significant difference in genotypes with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for chlorophyll fluorescence.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 9: Response of wheat genotypes to drought and high temperature for chlorophyll fluorescence at anthesis under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 10: Response of wheat genotypes to drought and high temperature for chlorophyll fluorescence at 15 days after anthesis under timely, late and very late sown conditions

Graphical representation of chlorophyll fluorescence under different drought condition at anthesis and 15 days after anthesis is shown in Fig. 9 and 10. Variation in chlorophyll fluorescence at D40, D65, D40+D65 and complete drought was found at anthesis and 15 days after anthesis with different sowing conditions.

4.2.5 Chlorophyll content (SPAD)

Table 20, 21 and 22 showed the reduction in chlorophyll content (SPAD) at anthesis and 15 days after anthesis under different drought and delayed sowing condition. Maximum reduction in chlorophyll content was found at 15 days after anthesis as compare to anthesis under all drought and delayed sown (timely, late and very late) condition.

Table 20 showed significant reduction in chlorophyll content under different drought and delayed sown condition. Average chlorophyll content for different drought stress condition varied between 24.6 to 38.6 (anthesis) and 20.4 to 27.6 (at 15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on chlorophyll content at anthesis (30.6 and 24.6) and at 15 days after anthesis (21.9 and 20.4) respectively, under timely sown condition.

Chlorophyll content showed significant difference in all genotypes and different drought condition. Significant difference was observed among drought and genotypes interaction at anthesis and 15 days after anthesis.

Average chlorophyll content for genotypes ranged from 24.1 to 44.2 (anthesis) and 17.3 30.5 (at 15 days after anthesis). Genotype WH-1105 (44.2 and 30.5) followed by HD-2967

(40.2 and 27.6) had maximum chlorophyll content at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in chlorophyll content among all genotypes in all drought conditions at anthesis and 15 days after anthesis under timely sown conditions.

Table 21 showed reduction in chlorophyll content at anthesis and 15 days after anthesis under different drought situation of late sown condition. Average chlorophyll content for different drought stress condition ranged from 17.5 to 25.5 (anthesis) and 17.2 to 23.9 (at 15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction on chlorophyll content at anthesis (18.9 and 17.5) and at 15 days after anthesis (18.5 and 17.2) respectively, under late sown condition.

All genotypes and different drought condition showed significant difference in chlorophyll content. Significant difference was observed for interaction effect of drought and genotypes at anthesis and 15 days after anthesis.

Average chlorophyll content for genotypes ranged from 16.9 to 29.3 (anthesis) and 13.7 to 28.9 (at 15 days after anthesis). Genotype DHTW-60 (29.3 and 28.9), HD-2967 (25.9 and 24.5) followed by WH-1105 (22.5 and 23.2) had maximum chlorophyll content at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in chlorophyll content among all genotypes in all drought conditions at anthesis and 15 days after anthesis under late sown conditions.

Result presented in Table 22 showed reduction in chlorophyll content at anthesis and 15 days after anthesis under very late sown condition. Average chlorophyll content for different drought stress condition ranged from 16.4 to 24.2 (anthesis) and 10.3 to 20.4 (at 15 days after anthesis). Drought condition of D40+D65 and complete drought showed significant reduction (more negative) on chlorophyll content at anthesis (18.4 and 16.4) and at 15 days after anthesis (10.4 and 10.3) respectively, under very late sown condition.

All genotypes and different drought condition showed significant difference in chlorophyll content. Significant difference was observed for interaction effect of drought and genotypes at anthesis and 15 days after anthesis.

Average chlorophyll content for genotypes ranged from 12.9 to 26.9 (anthesis) and 8.0 to 22.5 (at 15 days after anthesis). Genotype DHTW-60 (26.9 and 22.5), HD-2967 (25.5 and 19.0) followed by HTW-11 (21.9 and 15.7) had maximum chlorophyll content at anthesis and 15 days after anthesis respectively. Genotype AKAW-3717 showed more reduction in chlorophyll content among all genotypes in all drought conditions at anthesis and 15 days after anthesis under very late sown conditions.

Table 20: Response of wheat genotypes to drought and high temperature for chlorophyll content (SPAD) at anthesis and 15 days after anthesis under timely sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	29.2	27.8	25.6	23.1	15.1	**24.1**	20.7	17.3	16.3	16.6	15.5	**17.3**
C-306	35.6	33.4	33.0	28.4	26.9	**31.5**	26.6	26.0	22.8	20.7	18.7	**23.0**
DHTW-60	42.1	41.4	37.4	35.5	26.5	**36.6**	29.7	27.8	26.5	23.9	22.1	**26.0**
HD-2967	45.8	43.5	40.9	38.2	32.4	**40.2**	31.8	30.6	26.8	25.5	23.3	**27.6**
HTW-11	35.2	32.1	26.5	24.6	20.4	**27.8**	26.5	23.8	22.0	20.4	18.6	**22.3**
KUNDAN	37.1	35.1	33.4	28.9	23.6	**31.6**	28.7	26.4	24.2	20.9	19.1	**23.9**
WH-730	34.2	28.6	26.0	24.1	17.2	**26.0**	22.6	19.7	18.6	19.1	18.1	**19.6**
WH-1105	51.7	47.0	45.3	42.4	34.4	**44.2**	34.3	32.7	29.6	28.1	27.6	**30.5**
Mean (D)	**38.9**	**36.1**	**33.5**	**30.6**	**24.6**	**32.7**	**27.6**	**25.6**	**23.3**	**21.9**	**20.4**	**23.8**
CD at 5%	**D= 1.51, G= 1.91, DxG= 0.14**						**D= 0.81, G= 1.02, DxG= 2.29**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 21: Response of wheat genotypes to drought and high temperature for chlorophyll content (SPAD) at anthesis and 15 days after anthesis under late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	21.0	18.4	18.0	15.2	11.8	**16.9**	16.7	13.0	14.2	12.6	11.8	**13.7**
C-306	24.0	22.6	21.3	15.9	14.2	**19.6**	22.3	18.7	17.0	15.6	14.0	**17.5**
DHTW-60	32.2	30.7	29.0	28.0	26.9	**29.3**	32.7	28.9	29.8	27.4	25.8	**28.9**
HD-2967	30.3	28.4	25.0	22.7	23.1	**25.9**	27.9	25.4	26.0	21.8	21.2	**24.5**
HTW-11	24.5	23.7	20.9	17.5	16.3	**20.6**	23.5	21.7	21.1	19.9	17.9	**20.8**
KUNDAN	24.1	23.3	21.7	16.5	14.5	**20.0**	22.5	19.2	20.8	16.0	14.9	**18.7**
WH-730	21.3	20.3	19.6	15.4	13.3	**18.0**	19.8	16.2	16.9	12.7	11.5	**15.4**
WH-1105	26.7	23.8	22.2	20.2	19.8	**22.5**	25.9	22.8	24.9	21.7	20.7	**23.2**
Mean (D)	**25.5**	**23.9**	**22.2**	**18.9**	**17.5**	**21.6**	**23.9**	**20.7**	**21.3**	**18.5**	**17.2**	**20.3**
CD at 5%	**D= 0.73, G= 0.92, DxG= 2.07**						**D= 0.17, G= 1.22, DxG= 0.50**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 22: Response of wheat genotypes to drought and high temperature for chlorophyll content (SPAD) at anthesis and 15 days after anthesis under very late sown conditions

Genotype	Anthesis						15 Days after anthesis					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	17.0	15.9	11.6	10.2	9.7	**12.9**	12.4	10.1	8.2	5.1	4.3	**8.0**
C-306	22.5	20.9	16.1	12.0	11.4	**16.6**	16.2	12.2	9.1	7.6	8.6	**10.7**
DHTW-60	29.1	27.6	27.0	25.6	25.0	**26.9**	27.3	25.2	22.1	19.1	18.9	**22.5**
HD-2967	28.4	26.4	25.5	24.1	23.1	**25.5**	26.7	20.4	18.8	14.9	14.0	**19.0**
HTW-11	26.0	24.0	22.0	20.6	16.9	**21.9**	21.8	19.0	17.8	10.3	9.5	**15.7**
KUNDAN	23.6	21.5	20.4	18.3	15.0	**19.8**	20.2	17.5	14.2	8.7	8.7	**13.9**
WH-730	22.9	21.3	20.2	17.3	14.3	**19.2**	18.4	14.3	10.4	8.2	8.7	**12.0**
WH-1105	23.8	21.6	21.9	19.3	16.2	**20.6**	20.4	18.5	17.6	9.1	9.4	**15.0**
Mean (D)	**24.2**	**22.4**	**20.6**	**18.4**	**16.4**	**20.4**	**20.4**	**17.2**	**14.8**	**10.4**	**10.3**	**14.6**
CD at 5%	**D= 0.64, G= 0.81, DxG= 1.85**						**D= 0.11, G= 1.05, DxG= 0.38**					

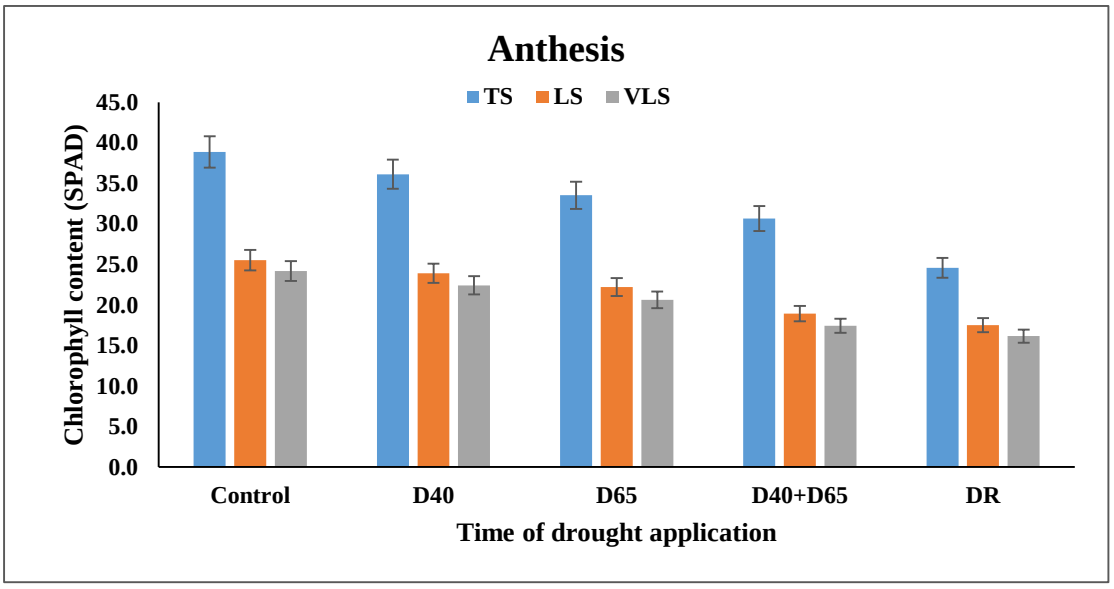
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 23: Mean sum of square of wheat genotypes for chlorophyll content in response to drought and high temperature at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Chlorophyll content (SPAD)	
		Anthesis	15 DAA
Replication	2	15.088**	8.073**
Genotype (G)	7	1010.742**	849.828**
Drought Treatment (D)	4	3951.651**	2119.825**
GxD	28	52.439**	14.342**
Sowing Time (S)	2	361.069**	251.388**
GxS	14	4.439**	2.101**
DxS	8	23.675**	14.924**
GxDxS	56	4.967**	1.837**
Error	238	0.112	0.036

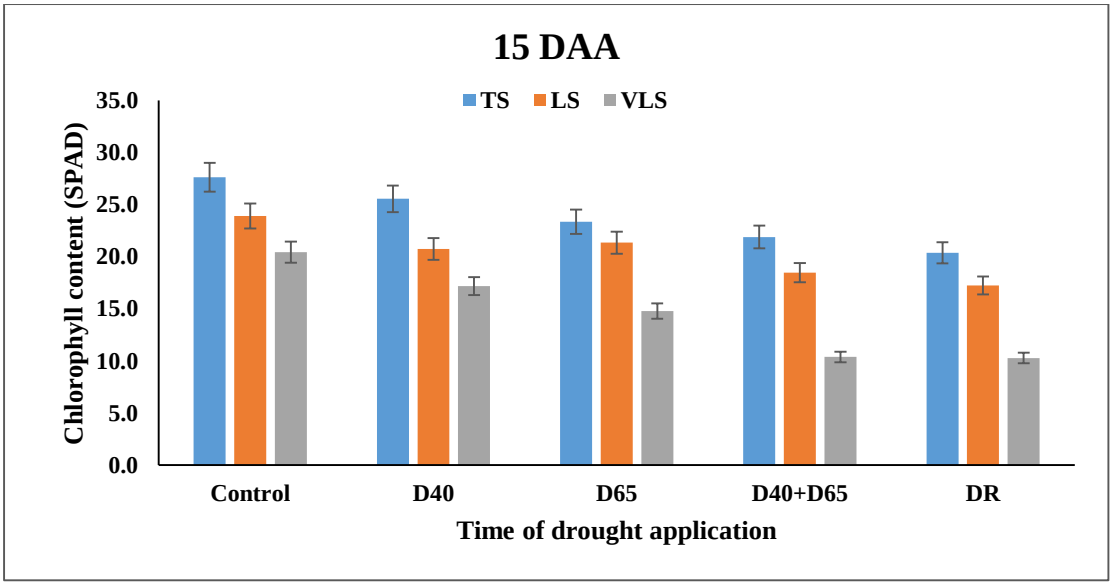
**** Significant at 1% of significance**

The mean sum of square for chlorophyll content at anthesis and 15 days after anthesis sown in Table 23 indicated significant difference due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was also found. This indicated that genotypes differed in their response to drought condition and sowing time of the trait under study.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 11: Response of wheat genotypes to drought and high temperature for chlorophyll content at anthesis under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 12: Response of wheat genotypes to drought and high temperature for chlorophyll content at 15 days anthesis (15 DAA) under timely, late and very late sown conditions

Graphical representation of chlorophyll content under different drought sowing condition at anthesis and 15 days after anthesis is shown in Fig. 11 and 12. Variation in chlorophyll content at D40, D65, D40+D65 and complete drought was found at anthesis and 15 days after anthesis under complete drought condition.

4.2.6 Stem reserve mobilization (%)

Stem reserve mobilization (%) in peduncle and penultimate internode recorded under different drought and delayed sowing condition shown in Table 24 and 25.

4.2.6.1 Peduncle reserve mobilization (%)

Stem reserve mobilization in peduncle showed significant fast remobilization in all genotypes along with time of drought application and delayed sowing condition (Table 24). Application of drought showed faster remobilization in timely, late and very late sown conditions and highest stem reserve mobilization was found in complete drought situation (29.1 %) under very late sown condition followed by late sown drought situation (24.2 %) whereas lowest stem reserve mobilization was observed in control (irrigated) (20.2 %) under timely sown condition. Average stem reserve mobilization in peduncle for different drought stress condition ranged from 13.3 to 24.9 % (timely sown), 16.7 to 29.7 % (late sown) and 21.3 to 34.8 % (very late sown). The drought situation of D40+D65 and complete drought resulted significant maximum stem reserve mobilization 24.1 and 24.9 % (timely sown), 28.4 and 29.7 % (late sown) and 33.4 and 34.8 % (very late sown) respectively. Significant difference was found in peduncle for reserve mobilization in all genotypes and different drought stress

condition. Significant difference was observed among drought and genotypes interaction under timely sown, late sown and very late sown condition.

Average peduncle reserve mobilization for genotypes ranged from 16.0 to 25.2 (timely sown), 19.5 to 30.0 % (late sown) and 24.3 to 34.5 % (very late sown). Genotype WH-1105 (25.2 %) followed by HD-2967 (22.7 %) had highest stem reserve mobilization under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (30.0 %) and HD-2967 (27.7 %) followed by WH-1105 (25.6 %) had high peduncle reserve mobilization under late sown condition and genotypes DHTW-60 (34.5 %) and HD-2967 (33.2 %) followed by HTW-11 (30.6 %) under very late sown condition. Genotype AKAW-3717 found lowest in average stem reserve mobilization among all genotypes under all drought and delayed sowing conditions.

4.2.6.2 Penultimate internode reserve mobilization (%)

Table 25 showed significant penultimate internode remobilization in all genotypes under time of drought application and delayed sowing condition. Application of drought increases stem reserve mobilization in timely, late and very late sown conditions and highest stem reserve mobilization was found in complete drought situation (21.2 %) under very late sown condition followed by late sown drought situation (15.6 %) and lowest stem reserve mobilization was observed in control (irrigated) condition (11.6 %) under timely sown condition.

Average penultimate internode reserve mobilization for different drought stress condition varied between 6.6 to 15.1 % (timely sown), 10.2 to 19.2 % (late sown) and 15.7 to 25.3 % (very late sown). The drought situation of D40+D65 and complete drought resulted significantly highest in penultimate internode reserve mobilization 14.1 and 15.1 % (timely sown), 18.4 and 19.2 % (late sown) and 24.0 and 25.3 % (very late sown) respectively. Significant difference was found for penultimate internode reserve mobilization in all genotypes and different drought stress condition. Interaction effect of drought and genotypes was found significant under timely sown, late sown and very late sown condition.

Average penultimate internode reserve mobilization for genotypes varied from 8.9 to 14.8 % (timely sown), 10.4 to 20.4 % (late sown) and 16.1 to 26.8 % (very late sown). Genotype WH-1105 (14.8 %) followed by HD-2967 (14.1 %) had highest stem reserve mobilization under timely sown condition. Combined effects of delayed sowing and drought stress showed that DHTW-60 (20.4 %) and HD-2967 (19.9 %) followed by WH-1105 (17.4 %) had high penultimate internode reserve mobilization under late sown condition and genotypes DHTW-60 (26.8 %) and HD-2967 (25.9 %) followed by HTW-11 (23.8 %) under very late sown condition. Genotype AKAW-3717 found lowest in average penultimate internode reserve mobilization among all genotypes under all drought and delayed sowing conditions.

Table 24: Response of wheat genotypes to drought and high temperature for stem reserve mobilization (%) in peduncle under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	9.1	13.6	17.0	19.7	20.7	**16.0**	12.5	16.7	20.2	23.4	24.9	**19.5**	15.8	20.1	26.2	29.4	30.0	**24.3**
C-306	11.6	16.1	20.1	23.1	23.9	**19.0**	15.1	18.8	22.9	26.4	27.4	**22.1**	17.1	21.5	27.9	30.0	31.4	**25.6**
DHTW-60	16.0	19.9	23.7	26.4	27.3	**22.7**	21.6	27.2	31.7	34.0	35.5	**30.0**	26.7	31.6	35.1	38.8	40.2	**34.5**
HD-2967	17.1	20.8	24.5	27.2	28.0	**23.5**	19.8	23.9	29.0	32.0	33.6	**27.7**	26.4	30.1	34.5	37.0	38.1	**33.2**
HTW-11	11.2	15.5	18.9	22.0	22.3	**18.0**	16.8	21.6	25.1	28.9	30.4	**24.6**	23.3	27.7	31.1	34.5	36.5	**30.6**
KUNDAN	13.7	17.3	21.6	24.6	25.7	**20.6**	16.1	20.5	24.7	27.7	28.8	**23.6**	20.9	25.6	29.5	32.6	33.9	**28.5**
WH-730	10.0	13.8	17.6	20.2	20.8	**16.5**	13.3	17.3	21.3	24.9	25.8	**20.5**	18.9	23.2	28.3	31.5	32.7	**26.9**
WH-1105	17.7	22.4	26.2	29.2	30.6	**25.2**	18.0	22.1	26.5	29.7	31.5	**25.6**	21.6	26.4	30.2	33.0	35.5	**29.3**
Mean (D)	**13.3**	**17.4**	**21.2**	**24.1**	**24.9**	**20.2**	**16.7**	**21.0**	**25.2**	**28.4**	**29.7**	**24.2**	**21.3**	**25.8**	**30.4**	**33.4**	**34.8**	**29.1**
CD at 5%	**D = 1.36, G = 1.46, DxG= 1.73**						**D = 1.42, G = 1.23, DxG = 1.86**						**D = 1.49, G = 1.50, DxG= 2.03**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 25: Response of wheat genotypes to drought and high temperature for stem reserve mobilization (%) in penultimate internode under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	3.8	7.6	9.5	11.6	12.2	**8.9**	5.4	9.2	11.9	13.7	13.7	**10.8**	11.1	14.7	16.7	18.5	19.7	**16.1**
C-306	5.9	9.5	11.9	13.1	14.5	**11.0**	9.0	12.3	14.0	15.8	16.9	**13.6**	12.2	15.0	17.5	19.4	20.8	**17.0**
DHTW-60	8.2	11.1	13.5	15.5	16.2	**12.9**	14.8	18.0	21.3	23.6	24.3	**20.4**	21.7	25.3	27.1	29.1	30.9	**26.8**
HD-2967	9.3	12.1	14.7	16.6	17.9	**14.1**	13.5	17.7	19.5	22.2	23.4	**19.3**	20.6	24.4	26.1	28.8	29.4	**25.9**
HTW-11	4.7	7.9	10.8	12.6	13.4	**9.9**	10.5	14.4	16.7	19.4	20.3	**16.3**	16.9	21.4	25.3	27.0	28.5	**23.8**
KUNDAN	6.7	10.1	12.9	14.5	15.3	**11.9**	9.9	13.7	15.5	17.2	18.8	**15.0**	14.1	17.0	20.2	23.8	24.5	**19.9**
WH-730	4.4	7.8	9.7	12.0	12.7	**9.3**	6.5	10.3	12.4	14.8	15.1	**11.8**	13.3	16.4	18.8	20.5	21.9	**18.2**
WH-1105	9.9	13.0	15.4	17.1	18.7	**14.8**	11.9	15.6	18.0	20.4	21.1	**17.4**	15.8	19.3	22.1	24.7	26.6	**21.7**
Mean (D)	**6.6**	**9.9**	**12.3**	**14.1**	**15.1**	**11.6**	**10.2**	**13.9**	**16.2**	**18.4**	**19.2**	**15.6**	**15.7**	**19.2**	**21.7**	**24.0**	**25.3**	**21.2**
CD at 5%	**D = 1.24, G = 1.31, DxG= 1.61**						**D = 1.27, G = 1.34, DxG= 1.76**						**D = 1.32, G = 1.41, DxG= 1.91**					

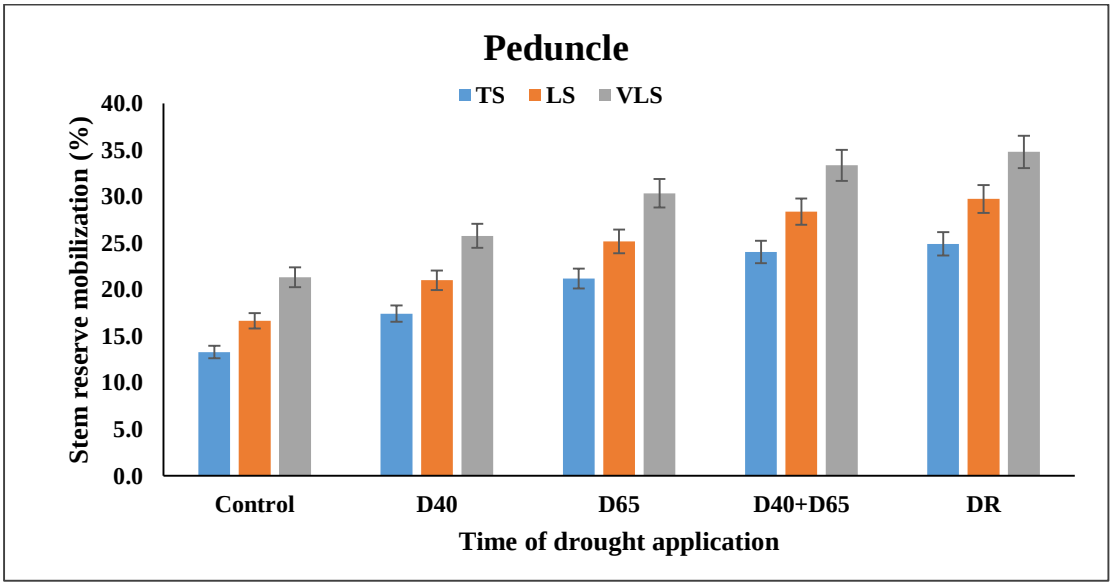
D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 26: Mean sum of square of wheat genotypes for stem reserve mobilization (%) in response to drought and high temperature in peduncle and penultimate internode under timely, late and very late sown condition

Source of variation	df	Stem reserve mobilization (%)	
		Peduncle	Penultimate internode
Replication	2	15.984**	6.653**
Genotype (G)	7	545.720**	465.881**
Drought Treatment (D)	4	3060.929**	1296.155**
GxD	28	0.817**	141.216**
Sowing Time (S)	2	262.680*	107.530**
GxS	14	0.376**	13.769**
DxS	8	14.619**	5.550**
GxDxS	56	0.345**	0.934**
Error	238	0.086	0.090

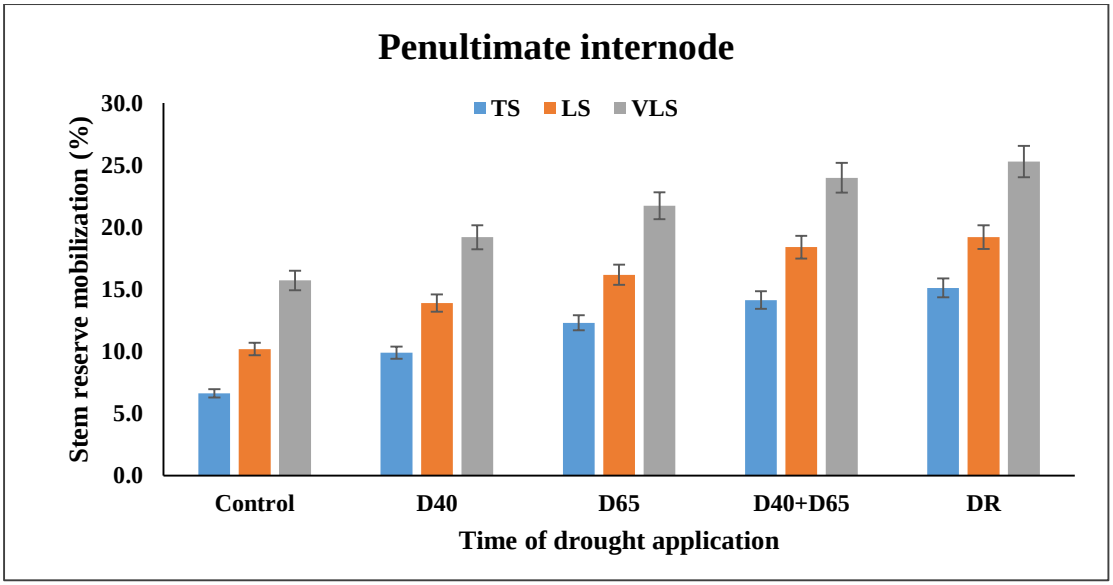
**** Significant at 1% of significance**

Table 26 showed mean sum of square for stem reserve mobilization in peduncle and penultimate internode. These results indicate that there is significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was also found significant. This indicated that genotypes differed in their response to drought condition and sowing time of the trait under study.



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 13: Response of wheat genotypes to drought and high temperature for stem reserve mobilization in peduncle under timely, late and very late sown conditions



D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 14: Response of wheat genotypes to drought and high temperature for stem reserve mobilization in penultimate internode under timely, late and very late sown conditions

Figure 13 and 14 showed graphical representation of stem reserve mobilization under different drought sowing condition in peduncle and penultimate internode respectively. Significant difference in stem reserved mobilization at D40, D65, D40+D65 and complete drought situation was observed in peduncle and penultimate internode.

4.3 BIOCHEMICAL PARAMETERS

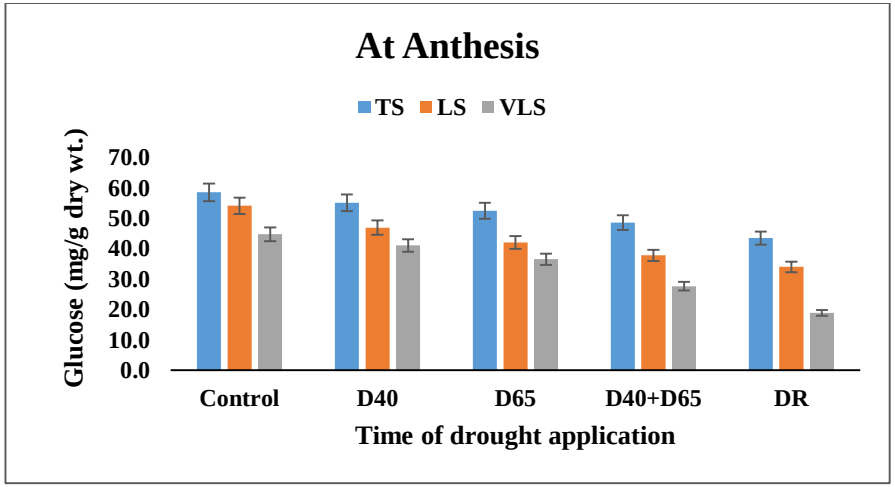
The biochemical parameters were observed on peduncle and penultimate internode at anthesis and 15 days after anthesis during both crop seasons and pooled mean data for metabolites and starch metabolizing enzyme activity are presented.

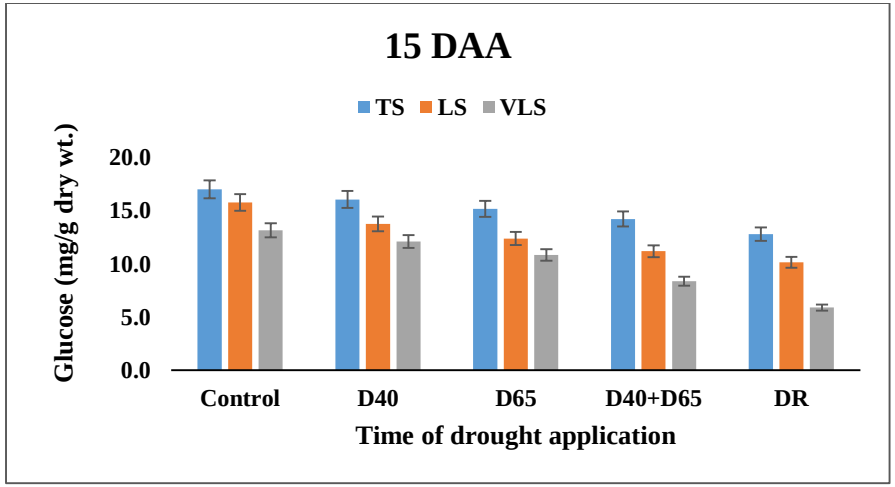
4.3.1 Metabolites

Glucose, fructose, sucrose, stem cell wall polysaccharide and total water soluble carbohydrate estimated in peduncle and penultimate internode.

4.3.1.1 Glucose (mg/g dry wt.)

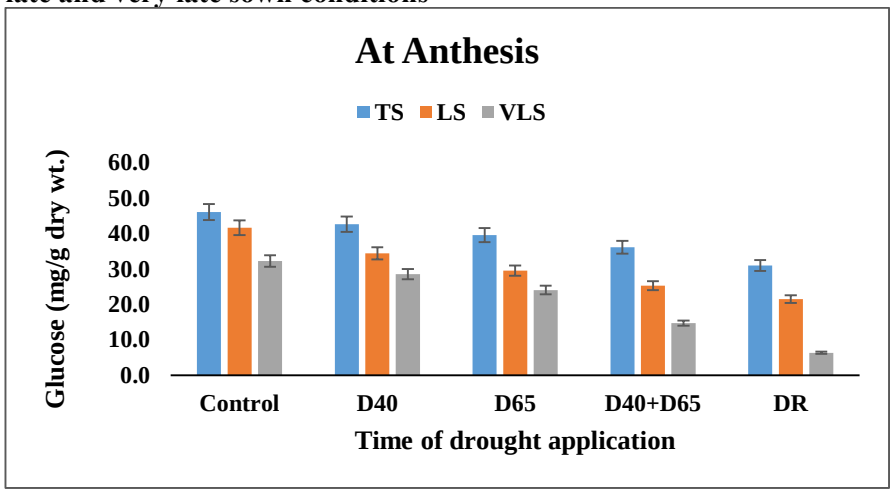
The graphical representation in Figure 15 and 16 demonstrate the glucose content in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA) respectively, under different drought and delayed sowing conditions. Significant reduction in glucose concentration observed under drought and late sown condition at anthesis and 15 days after anthesis. At 15 days after anthesis maximum reduction in glucose concentration compared to anthesis was observed. Significant difference in glucose at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis under stressed condition.

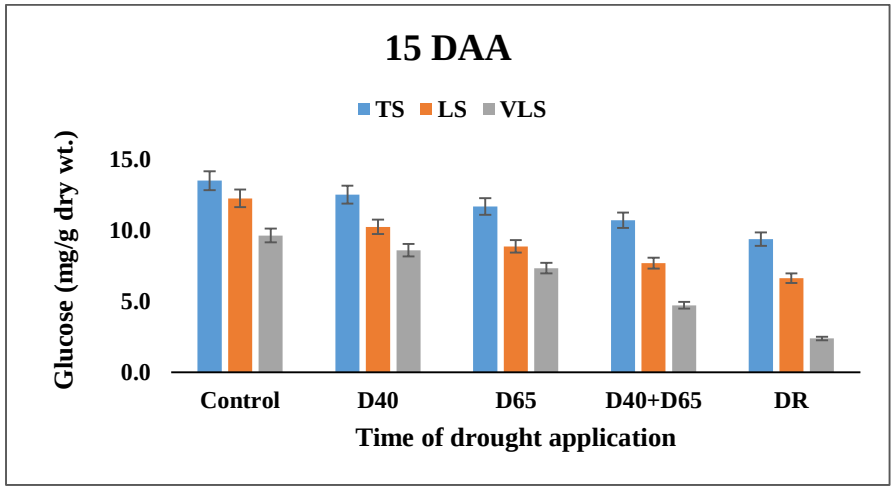




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 15: Response of wheat genotypes to drought and high temperature for glucose in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 16: Response of wheat genotypes to drought and high temperature for glucose in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

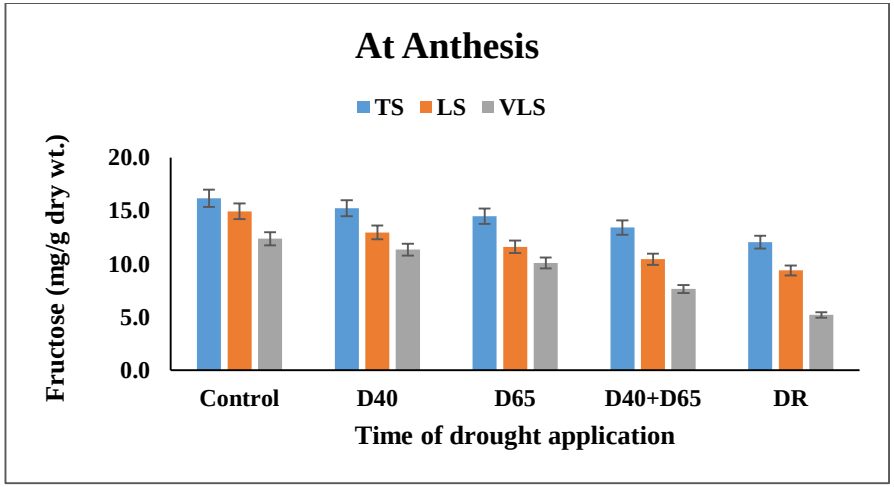
Average glucose content in peduncle under drought varied between 43.5 to 58.6mg/g dw (timely sown), 34.0 to 54.1 mg/g dw (late sown) whereas, 18.9 to 44.8 mg/g dw under different drought conditions at anthesis and at 15 days after anthesis peduncle glucose content ranged between 12.8 to 17.0 mg/g dw (timely sown), 10.1 to 15.1 mg/g dw (late sown) whereas, 5.9 to 13.2 mg/g dw (very late sown) under different delayed and drought condition. For penultimate internode average glucose content fluctuated between 30.9 to 46.0 mg/g dw (timely sown), 21.5 to 41.6 mg/g dw (late sown) and 6.3 to 32.2 mg/g dw (very late sown) at anthesis whereas, 9.4 to 13.5 mg/g dw (timely sown), 6.6 to 12.3 mg/g dw (late sown) and 2.4 to 9.6 mg/g dw (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum glucose concentration in peduncle (65.7 and 68.4 mg/g dw) and penultimate internode (49.9 and 53.0 mg/g dw) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum glucose content in peduncle and penultimate at anthesis and 15 days after anthesis respectively under late and very late sown condition (Appendix 1). Genotype AKAW-3717 showed maximum reduction in glucose content both in peduncle and penultimate internode among all genotypes in all drought conditions at anthesis and 15 days after anthesis under very late sown conditions.

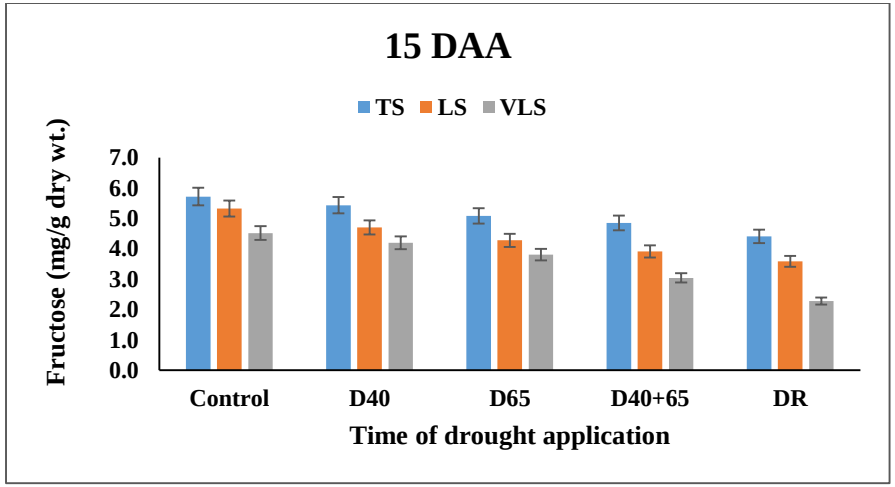
Table 27: Mean sum of square of wheat genotypes for glucose (mg/g dry wt.) in response to drought and high temperature in peduncle and penultimate at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	40.894**	0.687**	15.723**	0.441**
Genotype (G)	7	4546.707**	355.348**	2311.199**	183.716**
Drought Treatment (D)	4	9004.848**	689.890**	8887.295**	694.856**
GxD	28	41.835**	3.185**	37.773**	2.950**
Sowing Time (S)	2	1246.256**	95.026**	1175.113**	95.835**
GxS	14	8.571**	0.918**	12.228**	1.174**
DxS	8	143.729**	12.348**	159.219**	12.205**
GxDxS	56	4.648**	0.610**	7.835**	0.591**
Error	238	0.199	0.133	1.254	0.110

**** Significant at 1% of significance**

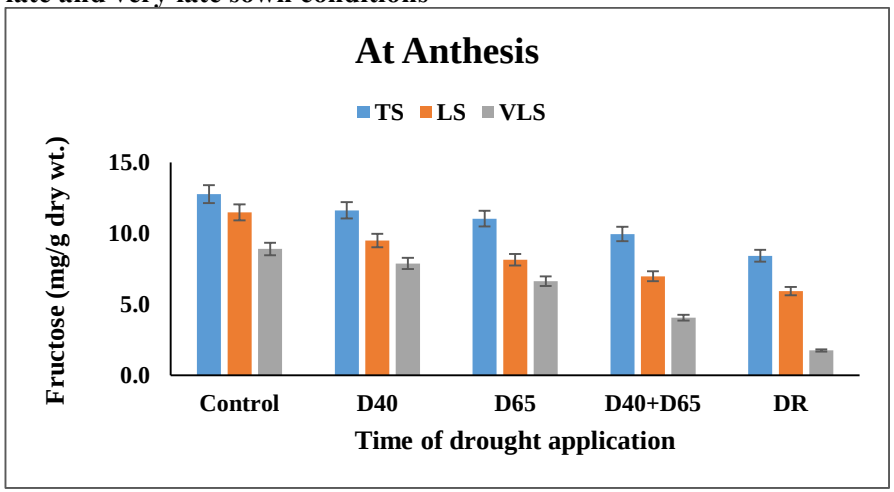
Table 27 showed mean sum of square for glucose in peduncle and penultimate internode at anthesis and 15 days after anthesis. These results indicate that there is significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was also found. This indicated that genotypes differed in their response to drought condition and sowing time of the traits under study.

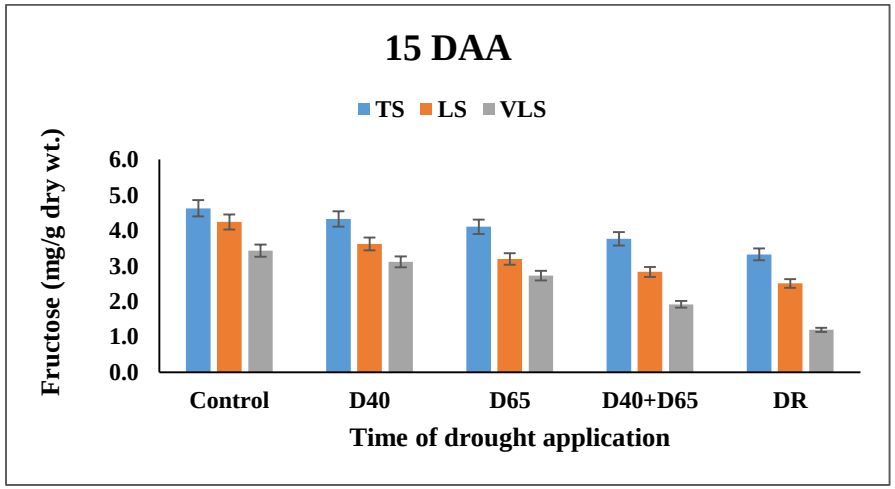




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 17: Response of wheat genotypes to drought and high temperature for fructose in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 18: Response of wheat genotypes to drought and high temperature for fructose in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

4.3.1.2 Fructose (mg/g dry wt.)

Results presented in Figure 17 and 18 indicate that fructose content in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA) respectively, under different drought and delayed sowing conditions. Under different drought and late sown condition significant reduction observed at anthesis and 15 days after anthesis both in peduncle and penultimate internode. Reduction in fructose concentration was more at 15 days after anthesis compared to anthesis. Significant difference in fructose content at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis under stressed condition. Maximum reduction in fructose concentration was observed at 15 days after anthesis under complete drought and D40+D65 followed by drought at 45 days after sowing.

Average fructose content in peduncle under drought varied between 12.1 to 16.2 mg/g dw (timely sown), 9.4 to 15.0 mg/g dw (late sown) whereas, 5.4 to 12.2 mg/g dw under different drought conditions at anthesis and at 15 days after anthesis peduncle fructose content ranged between 4.4 to 5.7 mg/g dw (timely sown), 3.6 to 5.3 mg/g dw (late sown) whereas, 2.3 to 4.5 mg/g dw (very late sown) under different delayed and drought condition. For penultimate internode average fructose content fluctuated between 8.4 to 12.8 mg/g dw (timely sown), 5.9 to 11.5 mg/g dw (late sown) and 8.9 to 10.7 mg/g dw (very late sown) at anthesis whereas, 3.3 to 4.6 mg/g dw (timely sown), 2.5 to 4.2 mg/g dw (late sown) and 1.2 to 3.4 mg/g dw (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum fructose concentration in peduncle (19.0 and 6.5 mg/g dw) and penultimate internode (18.1 and 6.4 mg/g dw) at anthesis and 15 days after anthesis (Appendix 2) respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum fructose content in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively under late and very late sown condition. Genotype AKAW-3717 showed maximum reduction in fructose content both in peduncle and penultimate internode among all genotypes in all drought conditions at anthesis and 15 days after anthesis under very late sown conditions.

Table 28: Mean sum of square of wheat genotypes for fructose (mg/g dry wt.) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	3.163**	0.330**	1.705**	0.281**
Genotype (G)	7	385.902**	37.013**	224.238**	22.296**
Drought Treatment (D)	4	633.607**	61.972**	604.663**	60.693**
GxD	28	2.756**	0.292**	3.008**	0.241**,
Sowing Time (S)	2	82.421**	7.758**	84.834**	7.677**
GxS	14	0.502**	0.053**	0.606**	0.067**
DxS	8	7.684**	0.731**	7.941**	0.669**
GxDxS	56	0.549**	0.050**	0.692**	0.059**
Error	238	0.020	0.004	0.068	0.002

**** Significant at 1% of significance**

Table 28 represent fructose mean sum of square at anthesis and 15 days after anthesis in peduncle and penultimate internode. These results indicate that there was significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. This indicated that genotypes differed in their response to drought condition and sowing time of the trait under study.

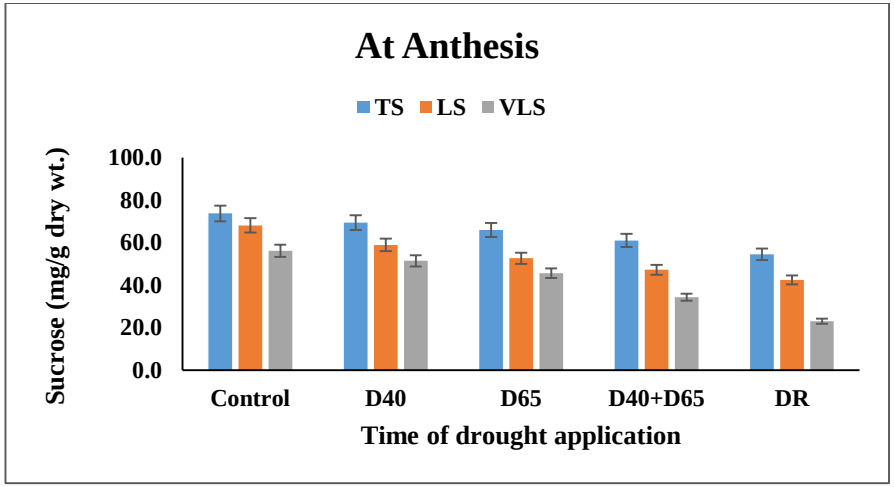
4.3.1.3 Sucrose (mg/g dry wt.)

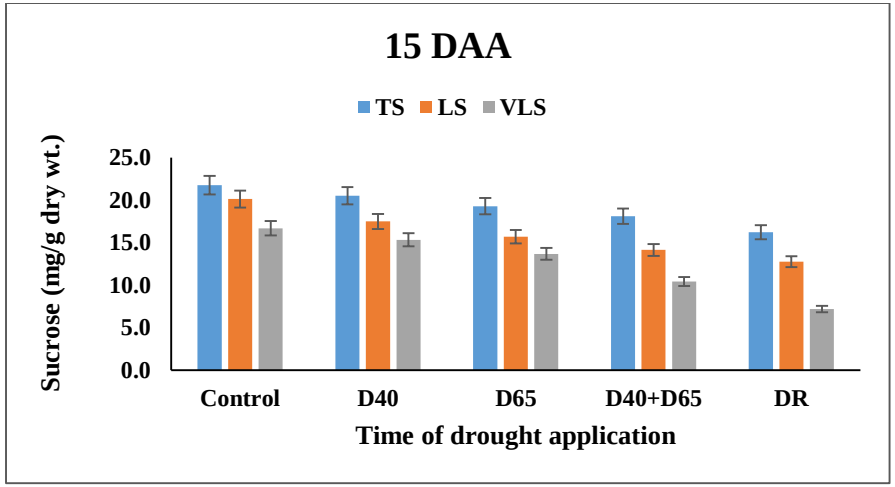
Figure 19 and 20 represent that sucrose content at anthesis and 15 days after anthesis (15 DAA) in peduncle and penultimate internode respectively, under different drought and delayed sowing conditions. Under different drought and late sown condition significant reduction observed at anthesis and 15 days after anthesis both in peduncle and penultimate internode. Reduction in fructose concentration was more at 15 days after anthesis compared to anthesis. Significant difference in fructose content at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis under stressed condition.

Average sucrose concentration in peduncle under drought varied between 54.6 to 73.8 mg/g dw (timely sown), 42.5 to 86.1 mg/g dw (late sown) whereas, 23.1 to 56.2 mg/g dw under different drought conditions at anthesis and at 15 days after anthesis peduncle sucrose concentration ranged between 16.2 to 21.8 mg/g dw (timely sown), 12.8 to 20.1 mg/g dw (late sown) whereas, 7.2 to 16.7 mg/g dw (very late sown) under different delayed and drought condition.

For penultimate internode average sucrose concentration fluctuated between 38.4 to 57.8 mg/g dw (timely sown), 26.4 to 52.1 mg/g dw (late sown) and 7.1 to 40.1 mg/g dw (very late sown) at anthesis whereas, 11.7 to 17.2 mg/g dw (timely sown), 8.2 to 15.5 mg/g dw (late sown) and 2.6 to 12.1 mg/g dw (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum sucrose concentration in peduncle (86.4 and 25.3, 82.8 and 24.5 mg/g dw) and penultimate internode (66.5 and 19.8, 62.8 and 18.6 mg/g dw) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum sucrose concentration in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively under late and very late sown condition (Appendix 3).

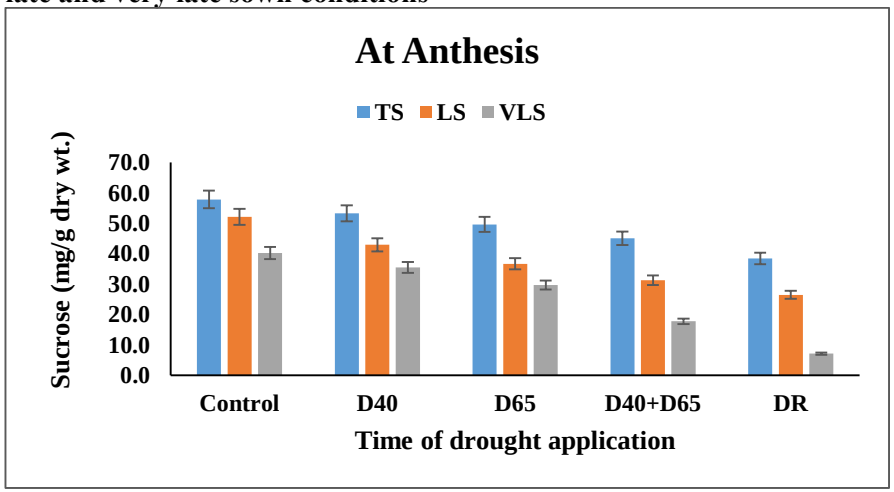
Genotype AKAW-3717 showed maximum reduction in sucrose concentration both in peduncle and penultimate internode among all genotypes in all drought conditions at anthesis and 15 days after anthesis under very late sown conditions.

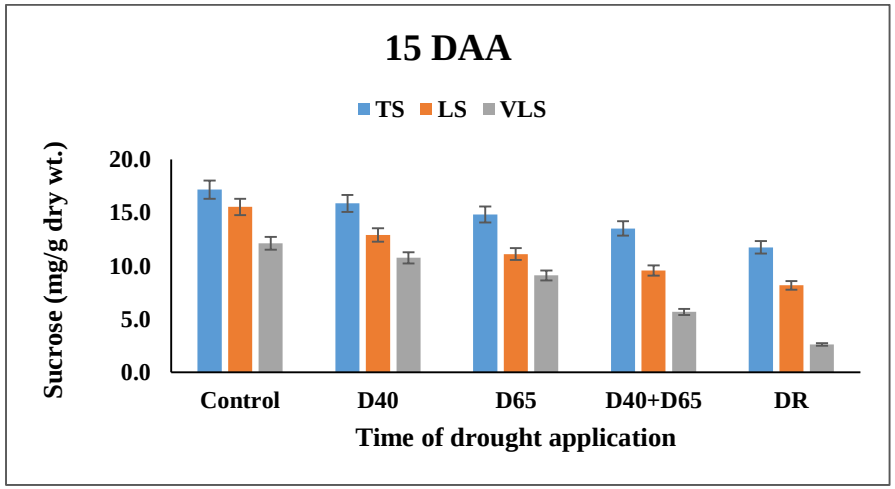




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 19: Response of wheat genotypes to drought and high temperature for sucrose in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 20: Response of wheat genotypes to drought and high temperature for sucrose in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Table 29: Mean sum of square of wheat genotypes for sucrose (mg/g dry wt.) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	73.500**	5.576**	37.024**	3.464**
Genotype (G)	7	7415.338**	607.319**	3755.216**	312.831**
Drought Treatment (D)	4	14637.893**	1199.716**	14683.895**	1210.468**
GxD	28	67.737**	5.424**	63.029**	5.129**
Sowing Time (S)	2	2084.047**	163.551**	1999.179**	162.515**
GxS	14	16.255**	1.091**	15.011**	1.326**
DxS	8	228.738**	19.540**	233.527**	19.680**
GxDxS	56	7.096**	0.585**	7.832**	0.666**
Error	238	0.419	0.032	0.217	0.029

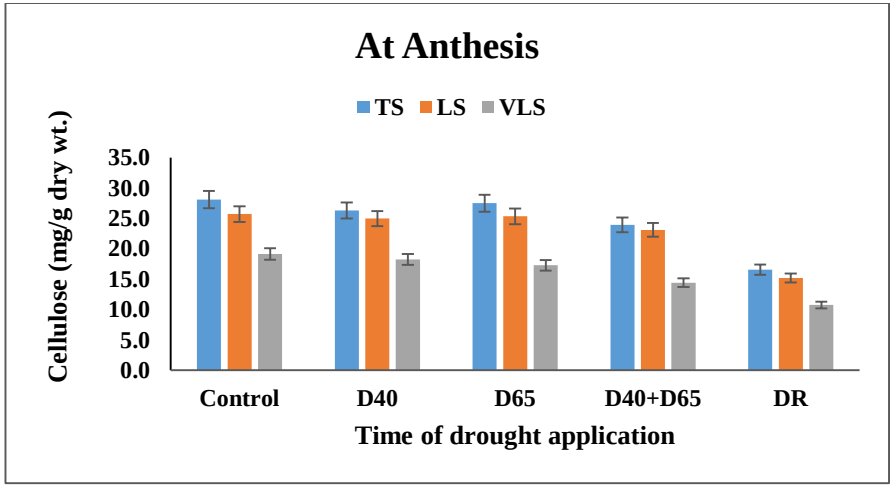
**** Significant at 1% of significance**

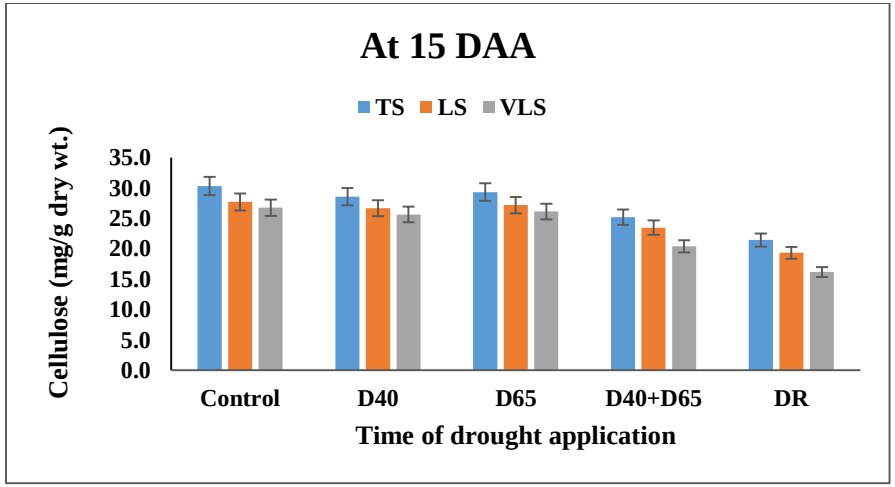
Mean sum of square presented in Table 29 for sucrose concentration at anthesis and 15 days after anthesis in peduncle and penultimate internode showed significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. This indicated that genotypes differed in their response to drought condition and sowing time of the trait under study.

4.3.1.4 Stem cell wall polysaccharide (cellulose, mg/g dry wt.)

Under different drought situation significant reduction in stem cell wall polysaccharide (cellulose) observed at anthesis and 15 days after anthesis both in peduncle and penultimate internode but increased with different delayed sowing condition showed in Figure 21 and 22. Reduction in cellulose concentration was more at anthesis compared to 15 days after anthesis. Significant difference in cellulose content at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis both in peduncle and penultimate internode under combined stress condition stressed condition.

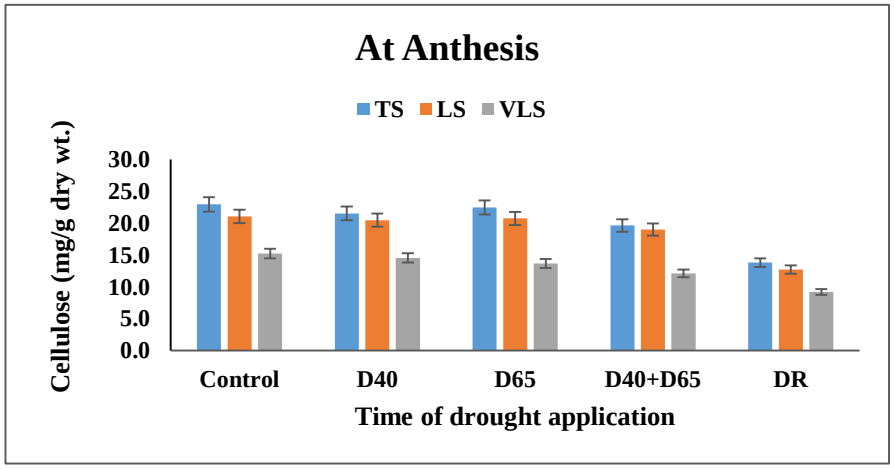
Stem cell wall polysaccharide (cellulose) in peduncle under drought varied between 16.6 to 28.1 mg/g dw (timely sown), 15.2 to 25.7 mg/g dw (late sown) whereas, 10.7 to 19.1 mg/g dw under different drought conditions at anthesis and at 15 days after anthesis peduncle cellulose varied between 21.5 to 30.3 mg/g dw (timely sown), 19.3 to 27.7 mg/g dw (late sown) whereas, 16.2 to 26.8 mg/g dw (very late sown) under different delayed and drought condition. For penultimate internode average cellulose ranged from 13.8 to 23.0 mg/g dw (timely sown), 12.7 to 21.1 mg/g dw (late sown) and 9.2 to 15.2 mg/g dw (very late sown) at anthesis whereas, 17.7 to 24.7 mg/g dw (timely sown), 16.0 to 22.6 mg/g dw (late sown) and 13.5 to 21.6 mg/g dw (very late sown) at 15 days after anthesis under different drought and delayed sowing condition.

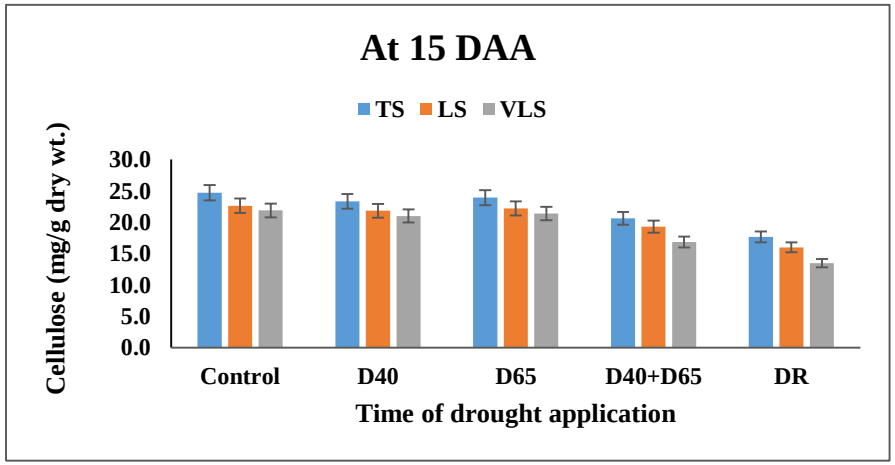




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 21: Response of wheat genotypes to drought and high temperature for stem wall polysaccharide (cellulose) in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 22: Response of wheat genotypes to drought and high temperature for stem wall polysaccharide (cellulose) in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotype WH-1105 and HD-2967 showed maximum cellulose (Appendix 4) in peduncle (26.6 and 29.0, 21.8 and 23.7 mg/g dw) and penultimate internode (26.1 and 28.7, 21.3 and 23.4 mg/g dw) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum cellulose in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition. Genotype AKAW-3717 was found least stem cell wall polysaccharide (cellulose) concentration at anthesis and 15 days after anthesis both in peduncle and penultimate internode among all genotypes in all drought conditions under delayed sown conditions.

Table 30: Mean sum of square of wheat genotypes for stem cell wall polysaccharide (cellulose, mg/g dry wt.) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	9.326**	8.321**	4.558**	5.153**
Genotype (G)	7	93.227**	103.892**	59.109**	65.248**
Drought Treatment (D)	4	2349.384**	1277.871**	1521.935**	799.439**
GxD	28	1.571**	1.737**	1.002**	1.123**
Sowing Time (S)	2	259.574**	156.971**	171.794**	98.853**
GxS	14	0.600**	0.400**	0.211**	0.217**
DxS	8	21.632**	14.510**	19.051**	9.598**
GxDxS	56	0.550**	0.596**	0.287**	0.335**
Error	238	0.043	0.052	0.024	0.037

**** Significant at 1% of significance**

The mean sum of square for stem cell wall polysaccharide (cellulose) in peduncle and penultimate internode at anthesis and 15 days after anthesis sown in Table 30 indicated significant difference due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was also found. This indicated that genotypes differed in their response to drought condition and sowing time of the traits under study.

4.3.1.5 Water soluble carbohydrates (mg/g dry wt.)

The graphical representation in Figure 23 and 24 demonstrate reduction in water soluble carbohydrates in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA) respectively, under different drought and delayed sowing conditions. Significant reduction in total water soluble carbohydrates observed under drought and late sown condition at anthesis and 15 days after anthesis. At anthesis water soluble carbohydrate concentration was found maximum in penultimate internode at anthesis but at 15 days after anthesis concentration was more in peduncle, respectively. Significant difference in water soluble carbohydrate at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis under stressed condition.

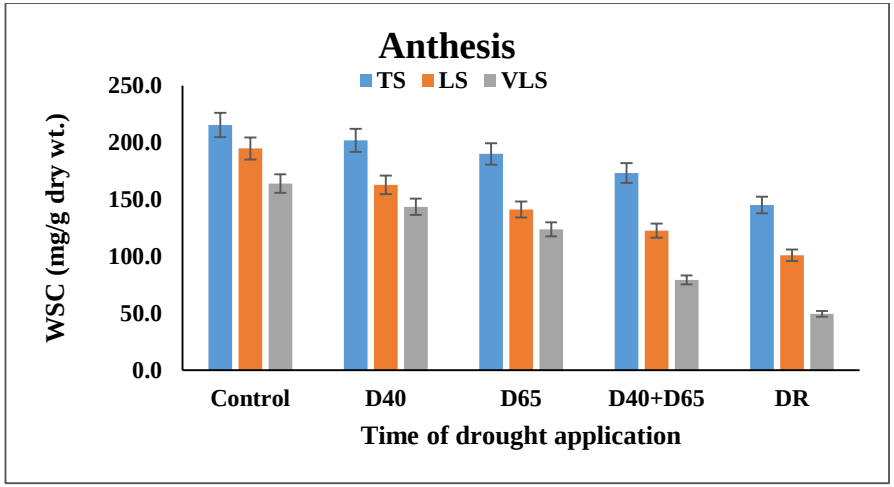
Average total water soluble carbohydrates in peduncle under drought varied between 145.2 to 215.5 mg/g dw (timely sown), 100.9 to 194.9 mg/g dw (late sown) whereas, 49.6 to 164.0 mg/g dw under different drought conditions at anthesis and at 15 days after anthesis peduncle water soluble carbohydrates varied between 113.6 to 163.5 mg/g dw (timely sown), 78.6 to 152.7 mg/g dw (late sown) whereas, 33.1 to 127.2 mg/g dw (very late sown) under different delayed and drought condition. For penultimate internode average water soluble carbohydrates ranged from 207.9 to 270.5 mg/g dw (timely sown), 160.5 to 254.7 mg/g dw (late sown) and 88.9 to 213.4 mg/g dw (very late sown) at anthesis whereas, 89.4 to 120.8 mg/g dw (timely sown), 68.5 to 111.7 mg/g dw (late sown) and 38.9 to 91.8 mg/g dw (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum water soluble carbohydrates in peduncle (250.0 and 188.0, 324.3 and 143.2 mg/g dw) and penultimate internode (235.3 and 178.4, 297.7 and 135.8 mg/g dw) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum water soluble carbohydrates in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition (Appendix 5). Genotype AKAW-3717 had least total water soluble carbohydrates at anthesis and 15 days after anthesis both in peduncle and penultimate internode among all genotypes in all drought conditions under delayed sown conditions.

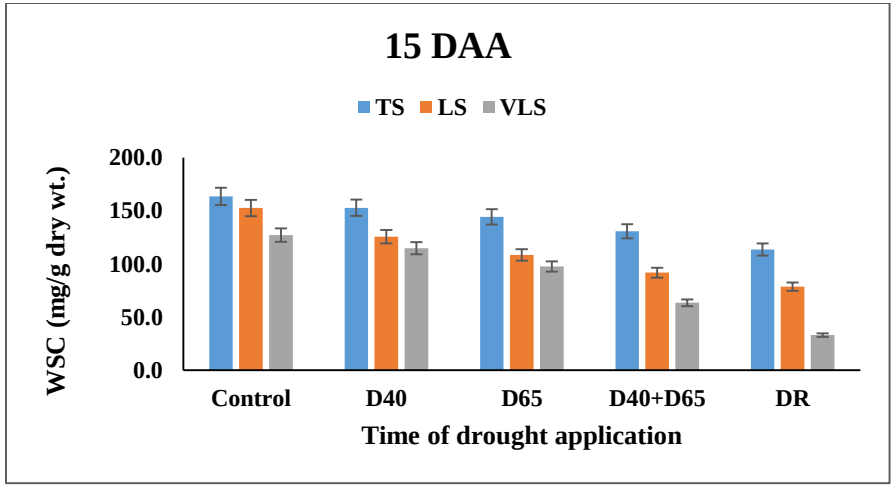
Table 31: Mean sum of square of wheat genotypes for water soluble carbohydrate (mg/g dry wt.) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	583.441**	377.686**	988.820**	209.936**
Genotype (G)	7	49533.263**	29568.620**	97553.763**	19632.526**
Drought Treatment (D)	4	173382.620**	101286.499**	200743.417**	38851.332**
GxD	28	886.638**	466.031**	738.164**	217.786**
Sowing Time (S)	2	19106.404**	11938.885**	28596.058**	5048.234**
GxS	14	178.040**	83.783**	164.999**	26.071**
DxS	8	1370.550**	1348.897**	3079.238**	530.993**
GxDxS	56	87.820**	46.400**	117.130**	15.807**
Error	238	4.042	2.267	4.111	1.268

**** Significant at 1% of significance**

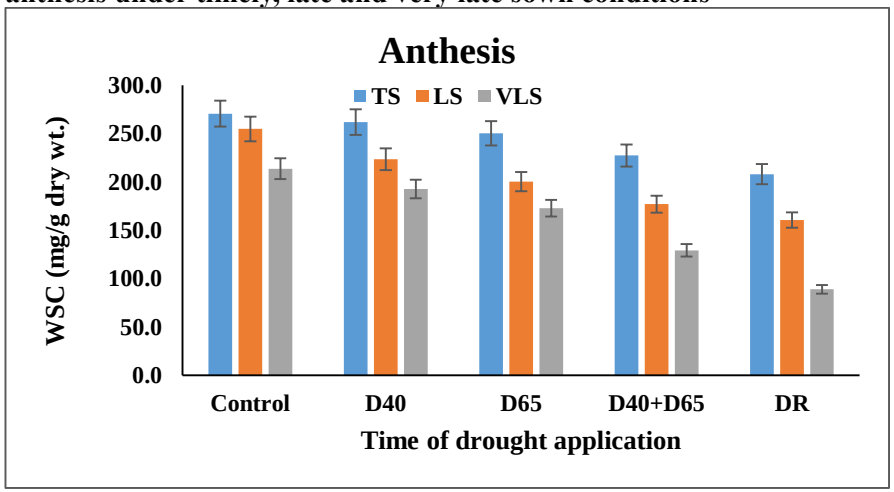
Table 31 showed the mean sum of square for water soluble carbohydrate at anthesis and 15 days after anthesis in peduncle and penultimate internode. These result indicated significant difference due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicated considerable variation for water soluble carbohydrate.

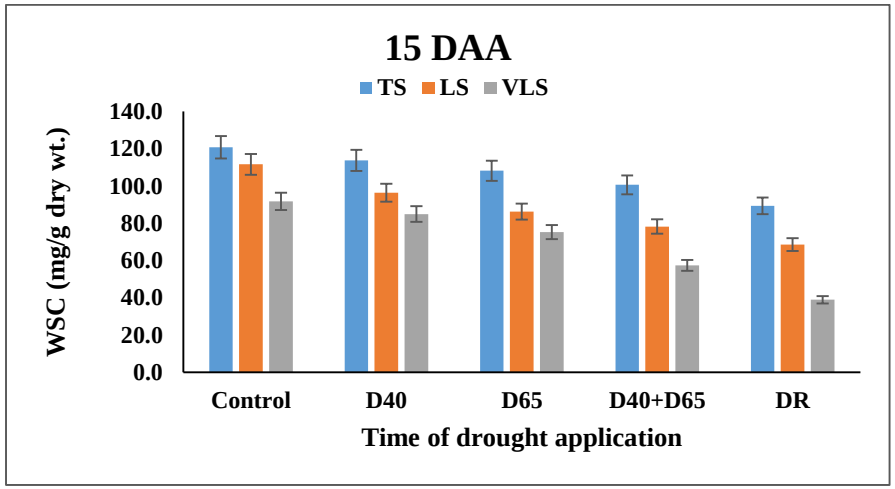




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 23: Response of wheat genotypes to drought and high temperature for water soluble carbohydrates in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 24: Response of wheat genotypes to drought and high temperature for water soluble carbohydrates in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

4.3.2 Carbohydrate metabolising enzymes

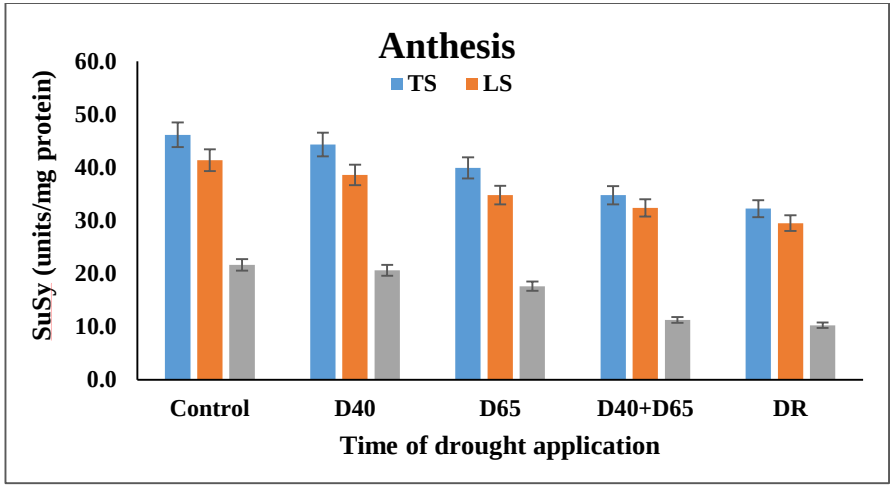
Carbohydrate metabolising enzymes *i.e.* sucrose synthase, invertase, starch branching enzyme, starch debranching enzyme and ADP-glucose pyrophosphorylase activity were studies at anthesis and 15 days after anthesis both in peduncle and penultimate internode.

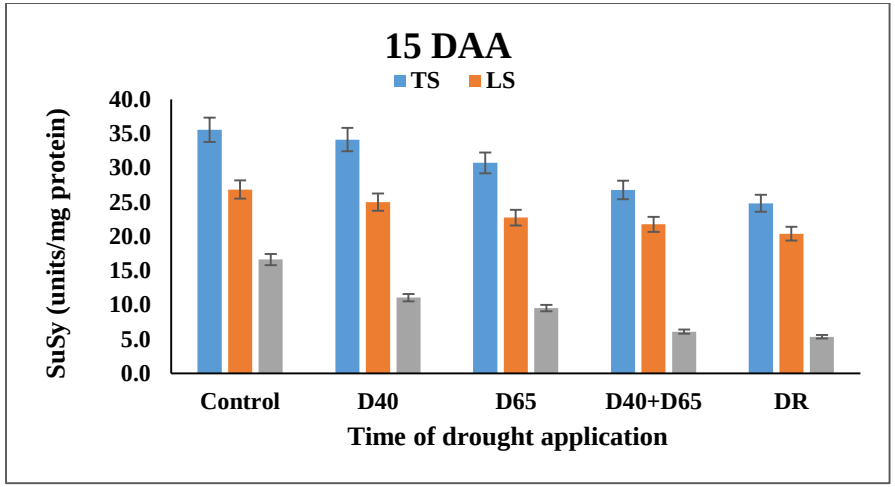
4.3.2.1 Sucrose synthase (SuSy, units/mg protein)

Sucrose synthase activities are given in Figure 25 and 26 showed reduction in enzyme activity under different drought situation and delayed sowing, respectively. Both peduncle and penultimate internode showed reduction in sucrose synthase activity under drought at anthesis and 15 days after anthesis (15 DAA). Combined effects of drought and high temperature (delayed sown) showed maximum reduction in enzyme activity under late and very late sown condition. Significant difference in SuSy activity at D40, D65, D40+D65 and complete drought situation was observed at anthesis and 15 days after anthesis under stressed condition both in peduncle and penultimate internode.

Average activity of sucrose synthase in peduncle under drought varied between 32.2 to 46.1 units/mg protein (timely sown), 29.5 to 41.3 units/mg protein (late sown) whereas, 10.3 to 21.6 units/mg protein under different drought conditions at anthesis and at 15 days after anthesis peduncle activity of sucrose synthase varied between 24.8 to 35.5 units/mg protein (timely sown), 20.4 to 26.8 units/mg protein (late sown) whereas, 5.3 to 16.6 units/mg protein (very late sown) under different delayed and drought condition. For penultimate internode activity of sucrose synthase ranged from 23.8 to 34.8 units/mg protein (timely sown), 18.2 to 26.6 units/mg protein (late sown) and 6.9 to 16.6 units/mg protein (very late sown) at anthesis whereas, 21.2 to 29.9 units/mg protein (timely sown), 16.1 to 22.9 units/mg protein (late sown) and 2.9 to 14.2 units/mg protein (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum activity of sucrose synthase in peduncle (51.7 and 39.9, 48.6 and 37.4 units/mg protein) and penultimate internode (39.0 and 33.7, 36.6 and 31.7 units/mg protein) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum activity of sucrose synthase in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition (Appendix 6). Genotype AKAW-3717 had least activity of sucrose synthase at anthesis and 15 days after anthesis both in peduncle and penultimate internode among all genotypes in all drought conditions under delayed sown conditions.

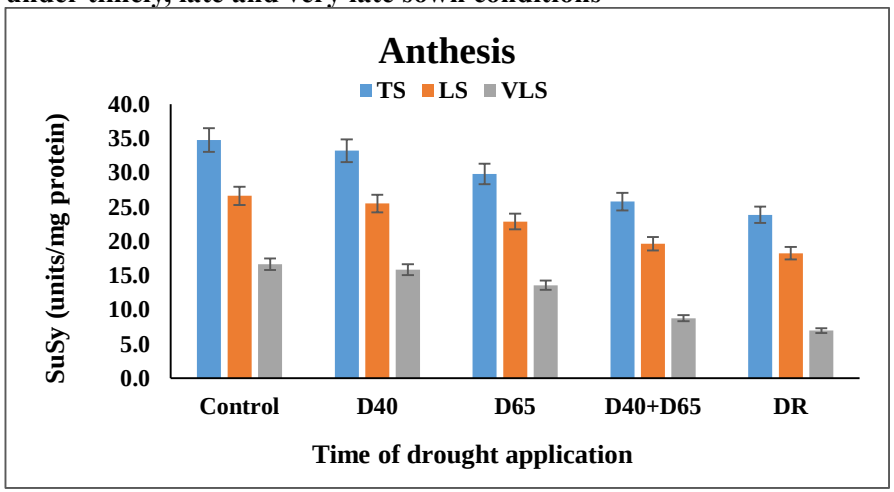
Significant decline in the sucrose synthase activity observed among all genotypes when the drought treatments were imposed at anthesis as well as 15 days after anthesis. All genotypes showed similar trends reduction both in peduncle and penultimate internode at anthesis and 15 days after anthesis. Genotype WH-1105 and HD-2967 (timely sown) and DHTW-60 and HD-2967 (late and very late sown condition) were found to have maximum sucrose synthase activity both in peduncle and penultimate internode under different drought situation.

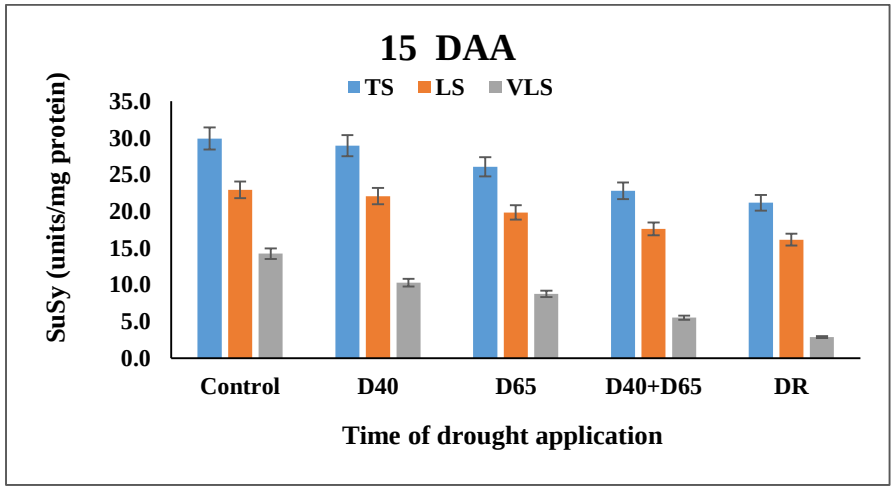




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 25: Response of wheat genotypes to drought and high temperature for sucrose synthase activity in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 26: Response of wheat genotypes to drought and high temperature for sucrose synthase activity in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Table 32: Mean sum of square of wheat genotypes for sucrose synthase activity (units/mg protein) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	29.054**	13.894**	19.1575**	9.492**
Genotype (G)	7	1,547.98**	800.524**	848.861**	569.371**
Drought Treatment (D)	4	10,697.49**	7364.523**	6012.844**	5428.666**
GxD	28	63.909**	42.052**	39.996**	34.146**
Sowing Time (S)	2	941.764**	699.813**	557.759**	537.131**
GxS	14	7.265**	2.110**	1.892**	1.691**
DxS	8	66.271**	50.837**	24.223**	19.812**
GxDxS	56	3.371**	2.344**	1.173**	0.861**
Error	238	0.149	0.088	0.107	0.060

**** Significant at 1% of significance**

Mean sum of square for sucrose synthase activity in peduncle and penultimate internode at anthesis and 15 days after anthesis in Table 32 indicated significant difference in genotypes with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for sucrose synthase.

4.3.2.2 Invertase alkaline (Units/mg protein)

Graphical representation (Figure 27 and 28) indicate reduction in invertase activity under delayed sowing with different drought situation in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA). Delayed sown condition under different drought application showed maximum reduction in invertase activity at 15 days after anthesis as compare to anthesis. Significant difference in peduncle invertase activity was found at different drought situation *i.e.* complete drought (anthesis) and D40, D65, D40+D65 and complete drought situation at 15 days after anthesis whereas, in penultimate internode D40, D65, D40+D65 and complete drought situation showed significant difference at anthesis and 15 days after anthesis.

Average invertase activity in peduncle under drought varied between 45.9 to 57.2 units/mg protein (timely sown), 41.3 to 54.7 units/mg protein (late sown) whereas, 29.1 to 40.4 units/mg protein under different drought conditions at anthesis and at 15 days after anthesis peduncle activity of invertase varied between 30.5 to 43.5 units/mg protein (timely sown), 18.8 to 34.0 units/mg protein (late sown) whereas, 12.6 to 24.1 units/mg protein (very late sown) under different delayed and drought condition. For penultimate internode activity of invertase ranged from 35.4 to 43.4 units/mg protein (timely sown), 30.4 to 39.2 units/mg protein (late sown) and 22.2 to 30.0 units/mg protein (very late sown) at anthesis whereas, 27.1 to 36.0

units/mg protein (timely sown), 18.2 to 26.7 units/mg protein (late sown) and 11.1 to 21.2 units/mg protein (very late sown) at 15 days after anthesis under different drought and delayed sowing condition.

Genotype WH-1105 and HD-2967 showed maximum activity of invertase in peduncle (53.6 and 44.2, 52.9 and 42.9 units/mg protein) and penultimate internode (43.0 and 34.8, 41.6 and 33.9 units/mg protein) at anthesis and 15 days after anthesis (Appendix 7) respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum activity of invertase in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition. The average activity was minimum in genotype AKAW-3717 at anthesis and 15 days after anthesis both in peduncle and penultimate among all genotypes in all drought conditions under delayed sown conditions.

Table 33: Mean sum of square of wheat genotypes for invertase alkaline activity (units/mg protein) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

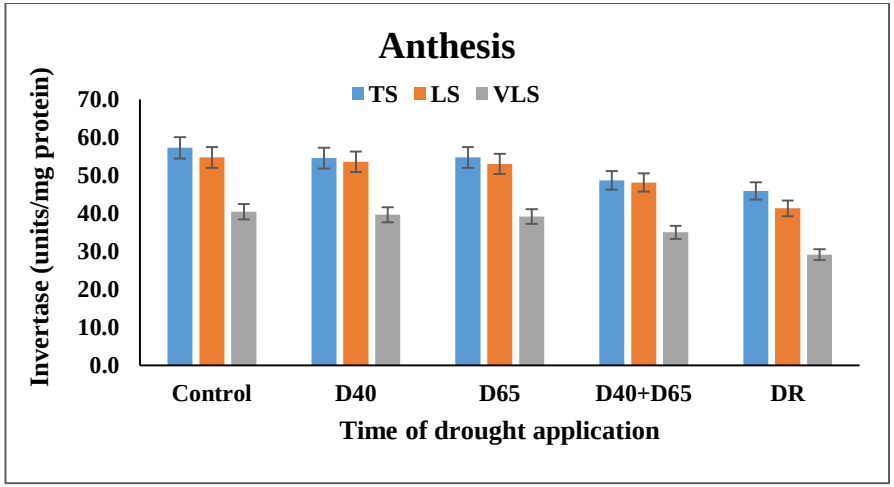
Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	37.115**	21.881**	20.609**	14.023
Genotype (G)	7	376.581**	1228.953**	138.881**	224.577
Drought Treatment (D)	4	5624.153**	5773.237**	3140.445**	3866.205
GxD	28	7.359**	37.070**	2.123**	9.246
Sowing Time (S)	2	507.766**	551.658**	305.911**	435.776
GxS	14	1.789**	4.971**	0.557**	2.302
DxS	8	59.136**	14.681**	17.528**	29.123
GxDxS	56	1.737**	4.494**	0.870**	3.061
Error	238	0.188	0.144	0.123	2.073

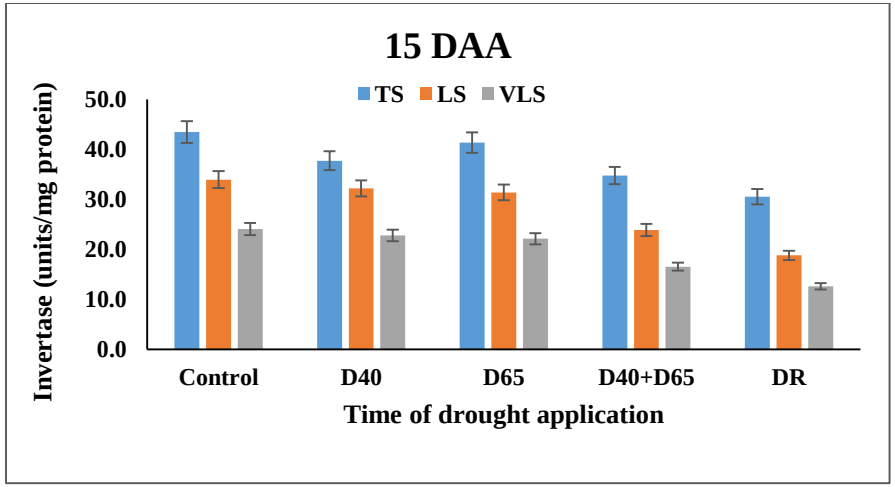
**** Significant at 1% of significance**

Mean sum of square presented in Table 33 for invertase alkaline activity at anthesis and 15 days after anthesis in peduncle and penultimate internode showed significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. This indicated that genotypes differed in their response to drought condition and sowing time of the traits under study.

4.3.2.3 Starch branching enzyme (SBE, units/mg protein)

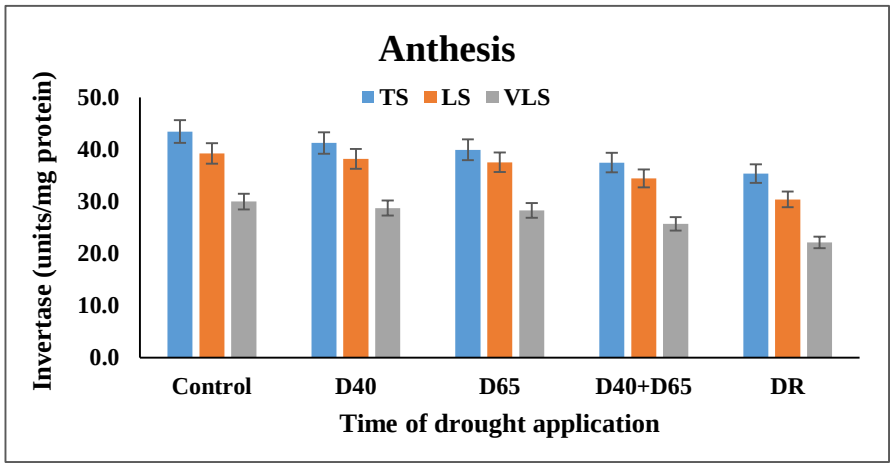
Figure 29 and 30 showed starching branching enzyme activity in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA). Application of drought treatments showed reduction in starch branching enzyme activity under delayed sown condition and maximum reduction was found at 15 days after anthesis. Drought situation *i.e.* D40, D65, D40+D65 and complete drought showed significant reduction at anthesis and 15 days after anthesis under stressed condition both in peduncle and penultimate internode.

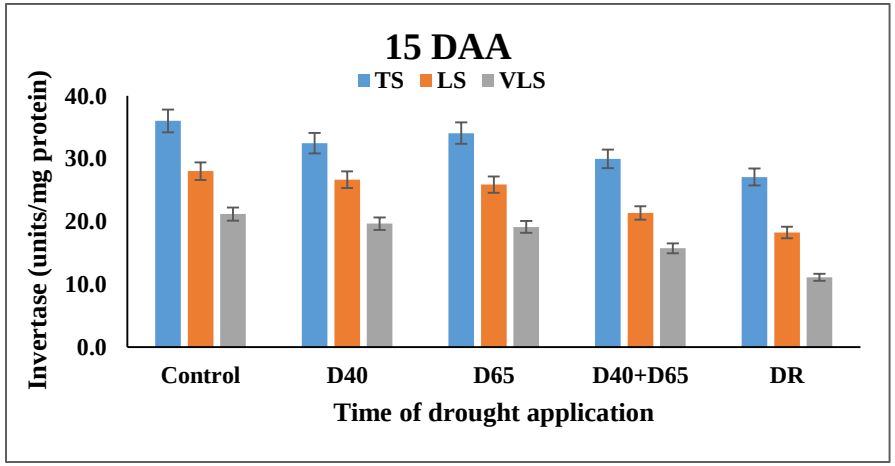




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

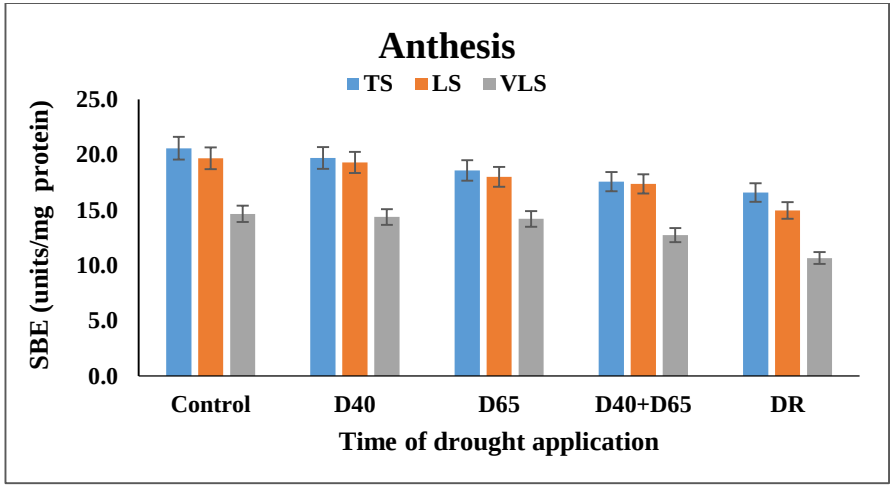
Fig. 27: Response of wheat genotypes to drought and high temperature for invertase alkaline activity in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions

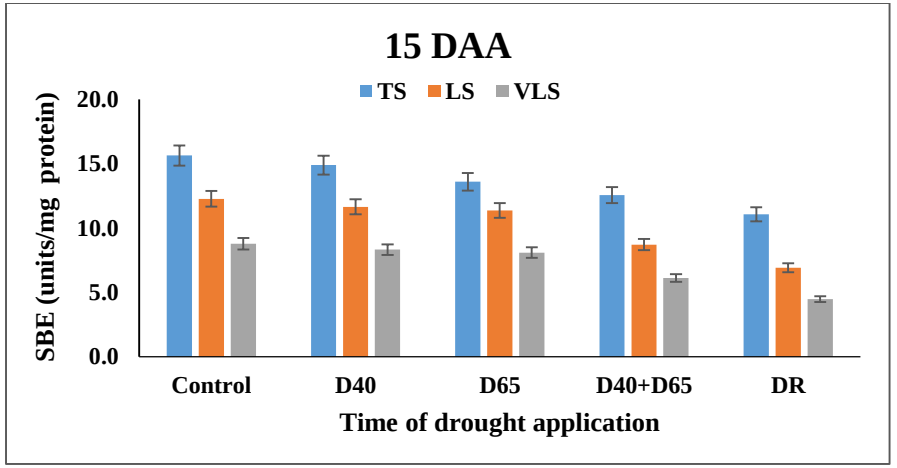




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

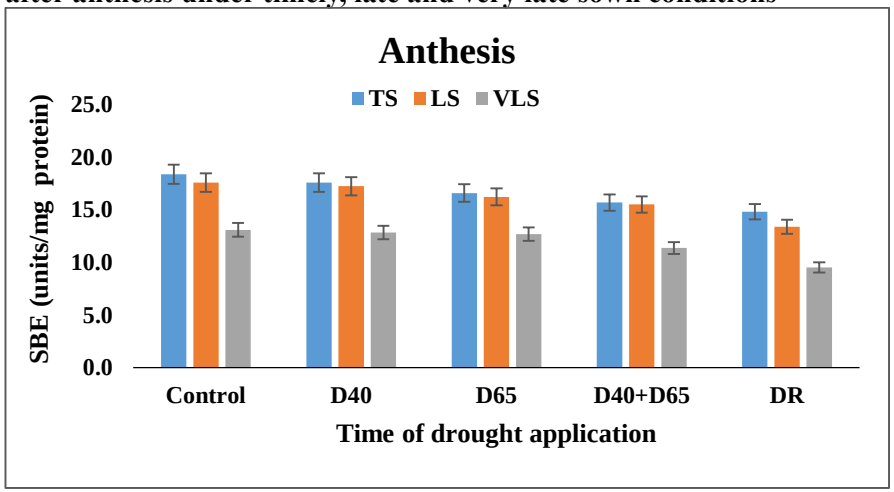
Fig. 28: Response of wheat genotypes to drought and high temperature for invertase alkaline activity in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

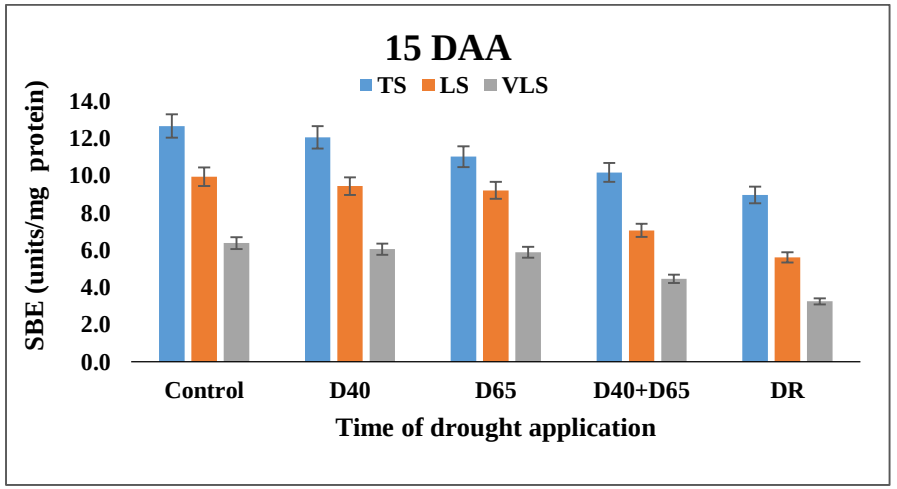




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 29: Response of wheat genotypes to drought and high temperature for starch branching enzyme activity in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 30: Response of wheat genotypes to drought and high temperature for starch branching enzyme activity in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Starch branching enzyme (SBE) average activity in peduncle under drought ranged from 16.6 to 20.6 units/mg protein (timely sown), 15.0 to 19.7 units/mg protein (late sown) whereas, 10.7 to 14.7 units/mg protein under different drought conditions at anthesis and at 15 days after anthesis peduncle activity of starch branching enzyme fluctuated between 11.1 to 15.6 units/mg protein (timely sown), 6.9 to 12.3 units/mg protein (late sown) whereas, 4.5 to 8.8 units/mg protein (very late sown) under different delayed and drought condition.

Mean penultimate internode activity of SBE ranged from 14.8 to 18.4 units/mg protein (timely sown), 13.3 to 17.5 units/mg protein (late sown) and 9.5 to 13.1 units/mg protein (very late sown) at anthesis whereas, 9.0 to 12.7 units/mg protein (timely sown), 5.6 to 9.9 units/mg protein (late sown) and 3.3 to 6.4 units/mg protein (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 showed maximum in activity of starch branching enzyme in peduncle (21.7 and 16.9, 20.4 and 15.4 units/mg protein) and penultimate internode (19.3 and 13.7, 18.2 and 12.4 units/mg protein) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum activity of starch branching enzyme in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition (Appendix 8).

Genotype AKAW-3717 showed minimum activity of starch branching enzyme both in peduncle and penultimate internode at anthesis and 15 days after anthesis among all genotypes and all drought conditions under delayed sown conditions.

Table 34: Mean sum of square of wheat genotypes for starch branching enzyme activity (units/mg protein) in response to drought and high temperature in peduncle and penultimate at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	2.284**	3.509**	3.562**	1.499**
Genotype (G)	7	85.410**	125.917**	68.001**	133.560**
Drought Treatment (D)	4	408.526**	854.585**	557.754**	511.554**
GxD	28	42.810**	2.332**	0.666**	7.778**
Sowing Time (S)	2	40.279**	90.012**	52.373**	51.912**
GxS	14	4.124**	0.136**	0.201**	0.656**
DxS	8	5.934**	4.283**	5.611**	2.943**
GxDxS	56	0.427**	0.434**	0.188**	0.353**
Error	238	0.039	0.019	0.024	0.012

**** Significant at 1% of significance**

Mean sum of square for starch branching enzyme activity in peduncle and penultimate internode at anthesis and 15 days after anthesis in Table 34 indicated significant difference in

genotypes with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for enzyme activity.

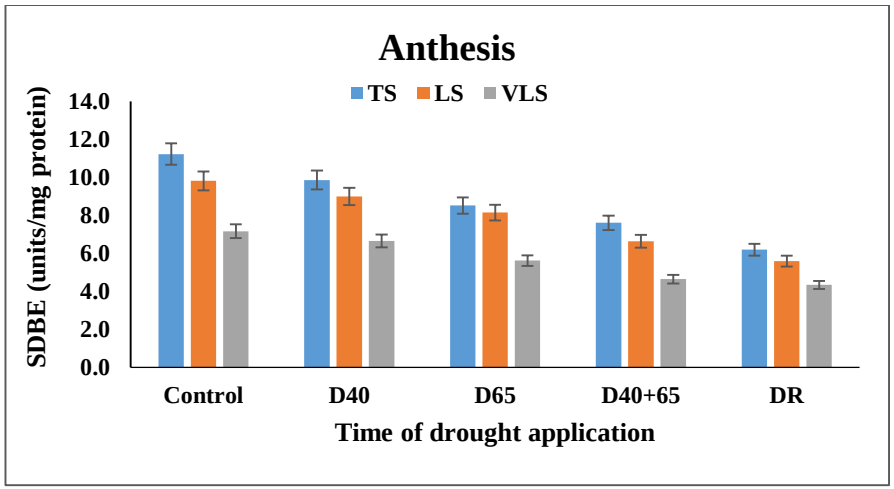
4.3.2.4 Starch debranching enzyme (SDBE, units/mg protein)

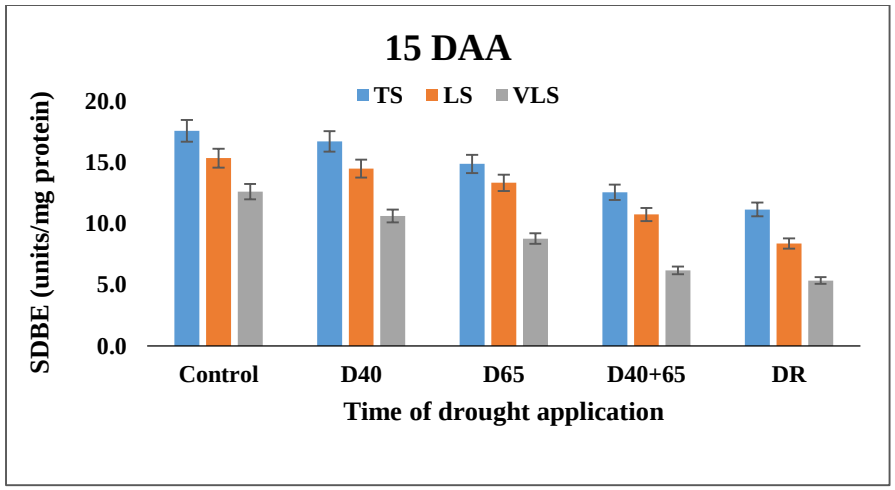
Figure 31 and 32 showed starching branching enzyme activity in peduncle and penultimate internode at anthesis and 15 days after anthesis (15 DAA). Application of drought treatments showed reduction in starch branching enzyme activity under different drought condition whereas, activity increased with delayed sown condition. Maximum enzyme activity was found at 15 days after anthesis as compare to anthesis under high temperature. Drought situation *i.e.* D40, D65, D40+D65 and complete drought showed significant reduction at anthesis and 15 days after anthesis under stressed condition both in peduncle and penultimate internode.

Starch debranching enzyme (SDBE) average activity in peduncle under drought ranged from 6.2 to 11.2 units/mg protein (timely sown), 5.6 to 9.8 units/mg protein (late sown) whereas, 4.3 to 7.2 units/mg protein under different drought conditions at anthesis and at 15 days after anthesis peduncle activity of starch debranching enzyme fluctuated between 11.2 to 17.6 units/mg protein (timely sown), 8.4 to 12.6 units/mg protein (late sown) whereas, 5.4 to 12.6 units/mg protein (very late sown) under different delayed and drought condition.

For penultimate internode activity of SBE ranged from 4.0 to 6.3 units/mg protein (timely sown), 3.0 to 5.5 units/mg protein (late sown) and 1.9 to 4.5 units/mg protein (very late sown) at anthesis whereas, 7.9 to 14.3 units/mg protein (timely sown), 7.1 to 12.5 units/mg protein (late sown) and 5.5 to 9.2 units/mg protein (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 founded maximum in activity of starch debranching enzyme in peduncle (11.0 and 17.0, 9.8 and 16.3 units/mg protein) and penultimate internode (6.1 and 14.1, 5.9 and 12.54 units/mg protein) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum activity of starch debranching enzyme in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition (Appendix 9).

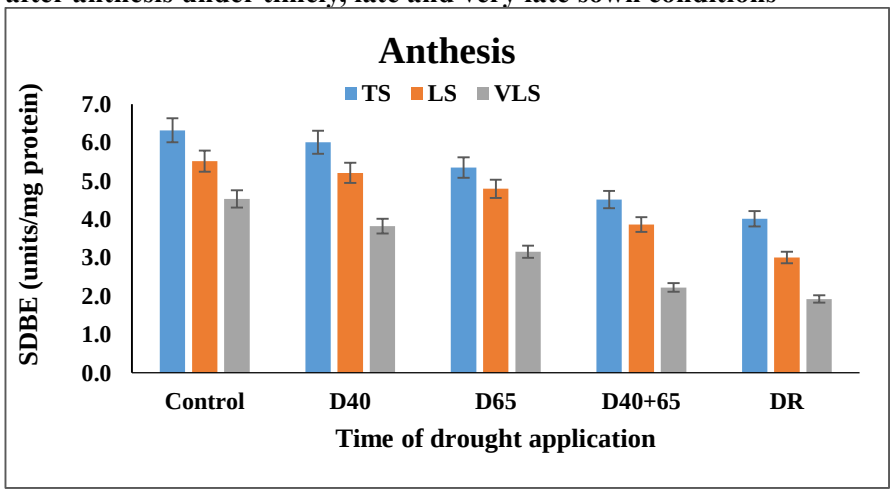
Genotype AKAW-3717 showed minimum activity of starch debranching enzyme both in peduncle and penultimate internode at anthesis and 15 days after anthesis among all genotypes and all drought conditions under delayed sown conditions.

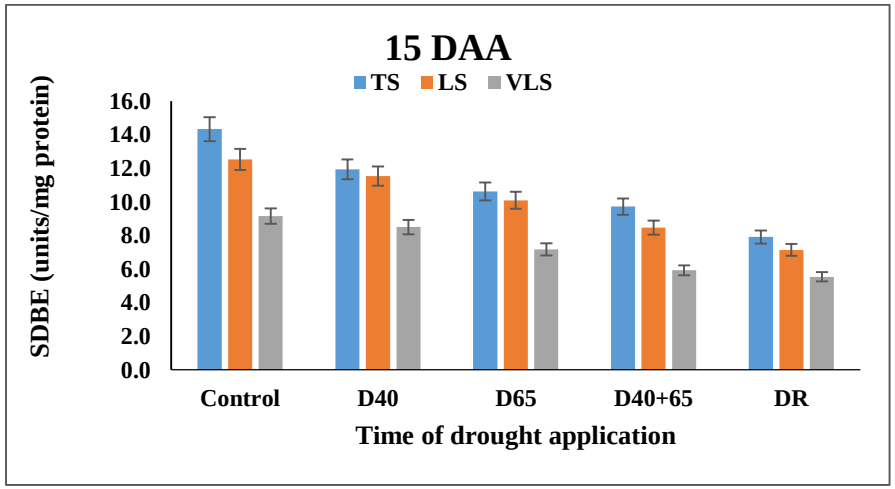




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

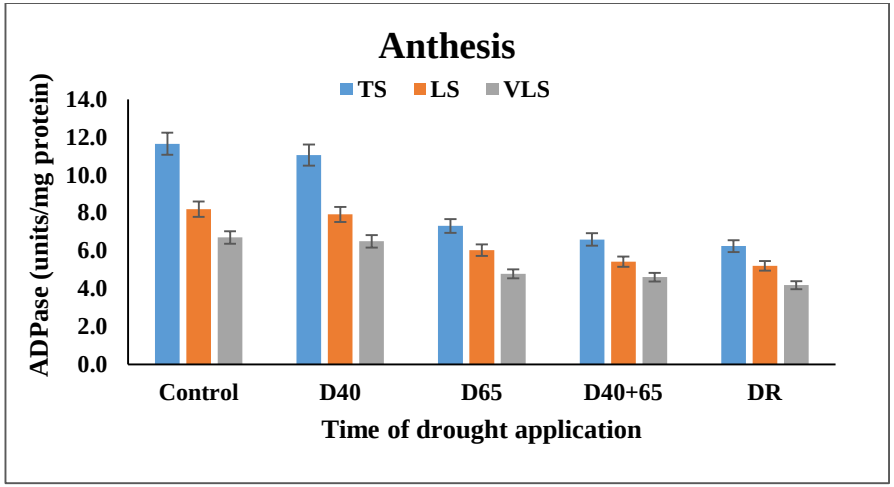
Fig. 31: Response of wheat genotypes to drought and high temperature for starch debranching enzyme activity in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions

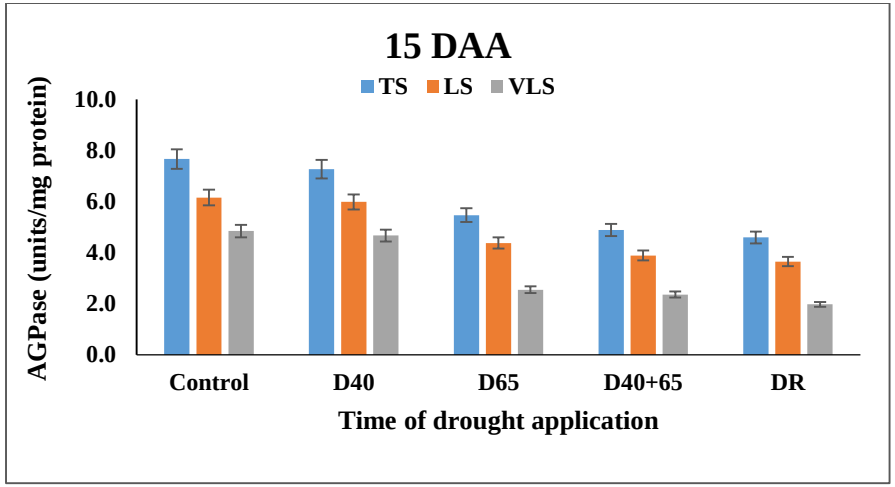




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

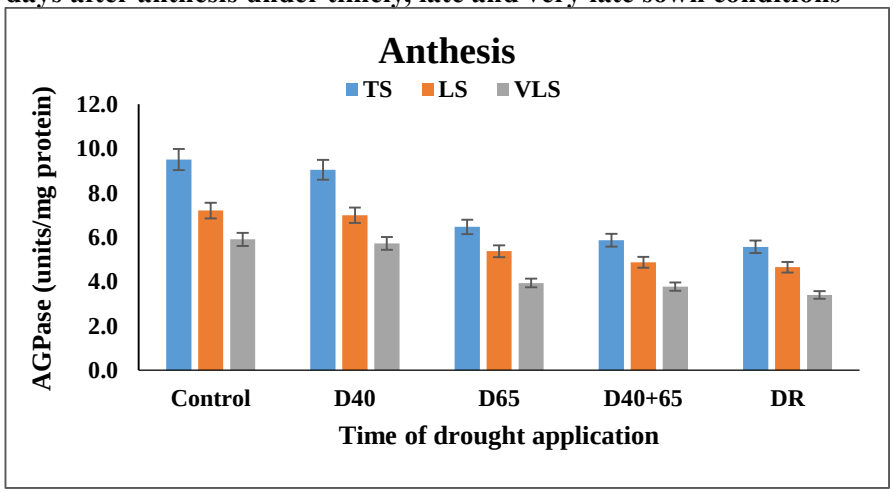
Fig. 32: Response of wheat genotypes to drought and high temperature for starch debranching enzyme activity in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

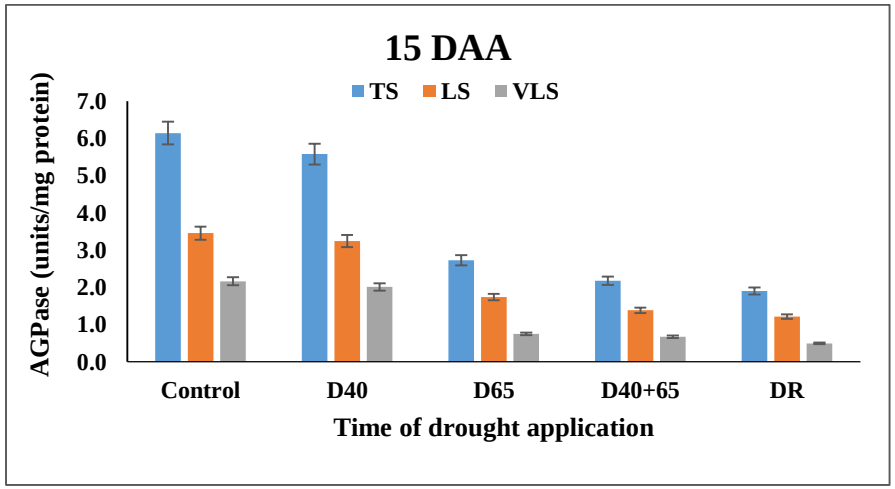




D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 33: Response of wheat genotypes to drought and high temperature for ADP-glucose pyrophosphorylase activity in peduncle at anthesis and 15 days after anthesis under timely, late and very late sown conditions





D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **TS-** Timely sown, **LS-** Late sown and **VLS-** Very late sown

Fig. 34: Response of wheat genotypes to drought and high temperature for ADP-glucose pyrophosphorylase activity in penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Table 35: Mean sum of square of wheat genotypes for starch debranching enzyme activity (units/mg protein) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	1.197**	3.596**	0.594**	2.483**
Genotype (G)	7	149.626**	120.500**	15.475**	184.401**
Drought Treatment (D)	4	241.452**	1071.385**	138.708**	498.874**
GxD	28	1.297**	1.451**	0.192**	0.835**
Sowing Time (S)	2	27.361**	111.288**	14.360**	60.785**
GxS	14	0.255**	0.352**	0.035**	0.137**
DxS	8	1.484**	4.185**	0.512**	3.114**
GxDxS	56	0.185**	0.262**	0.037**	0.267**
Error	238	0.008	0.024	0.003	0.014

**** Significant at 1% of significance**

Table 35 showed the mean sum of square for starch debranching enzyme at anthesis and 15 days after anthesis in peduncle and penultimate internode. These result indicated that there is genetic difference in genotypes under studies with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time was indicating considerable variation for starch debranching enzyme.

4.3.2.5 ADP-glucose pyrophosphorylase (AGPase, units/mg protein)

The result presented in Figure 33 and 34 showed AGPase activity under different drought condition with delayed sowing in peduncle and penultimate internode at anthesis and 15 days after anthesis. Graphical representation showed continuous reduction in ADP-glucose pyrophosphorylase activity with application of drought under timely, late and very late sown. Peduncle had more AGPase activity then penultimate internode at anthesis and reduction was found at 15 days after anthesis with drought and high temperature stress. Drought situation *i.e.* D40, D65, D40+D65 and complete drought showed significant reduction at anthesis and 15 days after anthesis under stressed condition both in peduncle and penultimate internode.

ADP-glucose pyrophosphorylase (AGPase) average activity in peduncle under drought ranged from 6.2 to 11.7 units/mg protein (timely sown), 5.2 to 8.2 units/mg protein (late sown) whereas, 4.2 to 6.7 units/mg protein under different drought conditions at anthesis and at 15 days after anthesis peduncle activity of ADP-glucose pyrophosphorylase fluctuated between 4.6 to 7.7 units/mg protein (timely sown), 3.6 to 6.2 units/mg protein (late sown) whereas, 2.0 to 4.8 units/mg protein (very late sown) under different delayed and drought condition. For penultimate internode activity of AGPase ranged from 5.6 to 9.5 units/mg protein (timely sown), 4.6 to 7.2 units/mg protein (late sown) and 3.4 to 5.9

units/mg protein (very late sown) at anthesis whereas, 1.9 to 6.1 units/mg protein (timely sown), 1.2 to 3.5 units/mg protein (late sown) and 0.5 to 29.2 units/mg protein (very late sown) at 15 days after anthesis under different drought and delayed sowing condition. Genotype WH-1105 and HD-2967 founded maximum in activity of ADP-glucose pyrophosphorylase in peduncle (11.0 and 8.8, 10.2 and 7.4 units/mg protein) and penultimate internode (9.3 and 6.2, 8.7 and 5.2 units/mg protein) at anthesis and 15 days after anthesis respectively, under timely sown condition whereas genotype DHTW-60 and HD-2967 had maximum activity of ADP-glucose pyrophosphorylase in peduncle and penultimate internode at anthesis and 15 days after anthesis respectively, under late and very late sown condition (Appendix 10). Genotype AKAW-3717 showed minimum in ADP-glucose pyrophosphorylase activity both in peduncle and penultimate internode at anthesis and 15 days after anthesis among all genotypes and all drought conditions under delayed sown conditions.

Table 36: Mean sum of square of wheat genotypes for ADP-glucose pyrophosphorylase activity (units/mg protein) in response to drought and high temperature in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown condition

Source of Variation	df	Peduncle		Penultimate internode	
		Anthesis	15 DAA	Anthesis	15 DAA
Replication	2	1.245**	0.598**	0.480**	0.247**
Genotype (G)	7	71.243**	55.114**	54.603**	45.282**
Drought Treatment (D)	4	353.975**	225.791**	241.711**	204.752**
GxD	28	1.539**	1.439**	1.114**	3.255**
Sowing Time (S)	2	47.849**	18.466**	27.425**	26.343**
GxS	14	0.291**	0.193**	0.245**	0.527**
DxS	8	11.462**	1.284**	4.201**	7.341**
GxDxS	56	0.170**	0.119**	0.107**	0.183**
Error	238	0.011	0.005	0.006	0.004

**** Significant at 1% of significance**

Mean sum of square presented in Table 34 for ADP-glucose pyrophosphorylase activity at anthesis and 15 days after anthesis in peduncle and penultimate internode showed significant variation due to genotypes (G), drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. This indicated that genotypes differed in their response to drought condition and sowing time of the traits under study.

4.4 Yield and yield attributes

Yield and its related attributes were recorded at the time of harvesting from selected tagged plants from each plots in three of replication.

4.4.1 Plant height (cm)

Significant reduction in plant height was observed in all genotypes along with time of drought application and delayed sowing condition (Table 37). Application of drought at different vegetative

growth period reduced the plant height in timely, late and very late sown conditions and maximum reduction in plant height was observed at D40+D65 and complete drought situation under late (91.3 and 85.1 cm) and very late sown (55.3 and 49.7 cm) whereas, minimum reduction was observed under timely sown condition (102.3 and 96.7 cm).

Average plant height for different drought stress condition ranged from 96.7 to 122.1 cm (timely sown), 85.7 to 104.0 cm (late sown) and 49.7 to 97.7 cm (very late sown). Maximum average plant height observed under timely sown (108.6 cm) whereas, late (95.1 cm) and very late sown (73.2 cm) condition showed maximum reduction in plant height. Significant difference was found for plant height in all genotypes and under different drought stress conditions. Significant interaction effects were found between genotypes and different drought conditions with delayed sowing condition. Average plant height for genotypes ranged from 91.7 to 141.3 cm (timely sown), 80.0 to 122.6 cm (late sown) and 62.0 to 94.2 cm (very late sown). Genotype DHTW-60 (141.3, 122.6 and 94.2 cm) and C-306 (127.4, 117.7 and 85.9 cm) followed by AKAW-3717 (114.8, 97.9 and 78.7 cm) had maximum plant height under timely, late and very late sown condition respectively. Genotype WH-1105 showed minimum average plant height among all genotypes under all drought and delayed sowing conditions.

4.4.2.1 Peduncle length (cm)

Table 38 showed reduction in peduncle length (cm) in all genotypes along with drought application and delayed sowing condition. Application of drought at different days after sowing reduced the peduncle length in timely, late and very late sown conditions and maximum reduction in peduncle length was found at D40+D65 and complete drought condition under late (36.1 and 34 1cm) and very late sown (17.8 and 16.3 cm) whereas, minimum reduction was observed under timely sown condition (38.5 and 37.1 cm).

Average peduncle length for different drought stress condition ranged from 37.1 to 44.1 cm (timely sown), 34.1 to 39.9 cm (late sown) and 16.3 to 35.4 cm (very late sown). Maximum average peduncle length observed under timely sown (40.3 cm) whereas, late (37.0 cm) and very late sown (25.0 cm) condition showed maximum reduction in mean peduncle length. Significant difference was found for peduncle length in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition. Average peduncle length for genotypes ranged from 32.8 to 53.0 cm (timely sown), 29.7 to 49.0 cm (late sown) and 18.8 to 31.4 cm (very late sown). Genotype DHTW-60 (53.0, 49.0 and 31.4 cm) and C-306 (48.0, 44.5 and 29.6 cm) followed by AKAW-3717 (42.0, 39.3 and 27.4 cm) had maximum peduncle length under timely, late and very late sown condition respectively. Genotype KUNDAN showed minimum average peduncle length among all genotypes under all drought and delayed sowing conditions.

Table 37: Response of wheat genotypes to drought and high temperature for plant height (cm) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	128.5	123.5	112.4	109.5	100.2	**114.8**	108.5	102.3	96.3	93.3	89.0	**97.9**	100.6	97.8	80.5	59.4	55.4	**78.7**
C-306	151.8	136.2	123.4	114.4	111.4	**127.4**	125.3	122.8	119.3	114.0	107.3	**117.7**	112.8	103.0	83.5	68.1	62.3	**85.9**
DHTW-60	155.2	148.5	139.1	132.8	130.7	**141.3**	128.5	126.0	123.7	120.7	114.3	**122.6**	124.8	110.8	90.7	76.3	68.2	**94.2**
HD-2967	112.4	107.4	98.9	96.2	91.8	**101.3**	95.7	92.0	90.5	84.7	79.7	**88.5**	92.3	81.1	73.1	51.6	46.8	**69.0**
HTW-11	115.0	103.3	94.0	91.5	86.5	**98.1**	92.5	88.5	83.0	79.9	71.3	**83.0**	87.1	78.2	70.3	49.5	42.4	**65.5**
KUNDAN	94.6	94.0	88.4	83.4	78.0	**87.7**	87.7	85.2	77.8	72.6	64.5	**77.6**	82.6	72.7	63.5	40.1	33.4	**58.5**
WH-730	119.9	113.4	105.7	102.5	92.9	**106.9**	103.0	96.2	92.0	89.6	86.8	**93.5**	95.5	84.2	75.7	54.0	51.2	**72.1**
WH-1105	99.4	95.3	93.7	88.3	81.7	**91.7**	90.5	86.8	79.2	75.8	67.9	**80.0**	85.5	75.5	68.1	43.0	37.8	**62.0**
Mean (D)	**122.1**	**115.2**	**107.0**	**102.3**	**96.7**	**108.6**	**104.0**	**100.0**	**95.2**	**91.3**	**85.1**	**95.1**	**97.7**	**87.9**	**75.7**	**55.3**	**49.7**	**73.2**
CD at 5%	**D= 1.87, G= 2.36, DxG= 5.28**						**D= 1.11, G= 1.41, DxG= 3.15**						**D= 1.14, G= 1.45, DxG= 3.23**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 38: Response of wheat genotypes to drought and high temperature for peduncle length (cm) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	48.9	44.2	40.9	38.5	37.3	**42.0**	44.6	40.1	39.3	37.4	35.1	**39.3**	39.5	30.8	28.3	19.5	18.7	**27.4**
C-306	54.4	50.5	48.0	44.9	42.3	**48.0**	47.1	46.1	45.3	44.1	39.9	**44.5**	45.0	32.4	30.1	20.8	19.5	**29.6**
DHTW-60	58.0	55.2	52.3	51.0	48.7	**53.0**	53.9	50.6	48.4	47.3	44.6	**49.0**	42.1	37.0	30.6	24.5	22.8	**31.4**
HD-2967	37.7	36.2	35.6	34.5	34.3	**35.7**	34.3	33.4	32.2	32.1	30.9	**32.6**	31.5	27.3	24.5	15.2	14.0	**22.5**
HTW-11	38.4	37.5	36.6	35.8	34.9	**36.6**	36.8	34.9	34.1	33.3	31.8	**34.2**	32.8	28.6	25.5	16.3	15.2	**23.7**
KUNDAN	34.8	33.7	33.2	32.1	30.2	**32.8**	31.4	30.4	29.9	29.2	27.6	**29.7**	25.8	22.9	20.7	13.2	11.2	**18.8**
WH-730	37.0	35.0	34.2	33.9	33.0	**34.6**	32.6	32.1	31.3	31.0	30.1	**31.4**	28.9	26.3	23.6	14.6	12.4	**21.2**
WH-1105	43.7	41.0	38.3	37.5	36.2	**39.3**	38.1	36.8	35.4	34.4	32.9	**35.5**	37.3	29.7	26.2	18.0	16.5	**25.5**
Mean (D)	**44.1**	**41.7**	**39.9**	**38.5**	**37.1**	**40.3**	**39.9**	**38.1**	**37.0**	**36.1**	**34.1**	**37.0**	**35.4**	**29.4**	**26.2**	**17.8**	**16.3**	**25.0**
CD at 5%	**D= 0.31, G= 0.40, DxG= 0.89**						**D= 0.38, G= 0.43, DxG= 1.08**						**D= 0.45, G= 0.57, DxG= 1.28**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

4.4.2.2 Peduncle dry weight (mg)

Peduncle dry weight (mg) presented in Table 39 showed reduction in dry weight in all genotypes under drought application and delayed sowing condition. Different drought application showed reduction in peduncle dry weight in all (timely, late and very late) sown conditions. Maximum reduction in peduncle dry weight was found at D40+D65 and complete drought situation under late (259.5 and 245.3 mg) and very late sown (128.2 and 117.8 mg) whereas, minimum reduction was observed under timely sown condition (276.8 and 266.6 mg).

Average peduncle dry weight for different drought stress condition ranged from 266.6 to 317.6 mg (timely sown), 245.3 to 287.1 mg (late sown) and 117.8 to 254.8 mg (very late sown). Maximum average peduncle dry weight observed under timely sown (289.5 mg) whereas, combination of late (266.4 mg) and very late sown (180.0 mg) condition showed maximum reduction in mean peduncle dry weight. Significant difference was found for peduncle dry weight in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition. Average peduncle dry weight for genotypes ranged from 215.2 to 412.4 mg (timely sown), 195.0 to 380.6 mg (late sown) and 123.2 to 244.3 mg (very late sown).

Genotype DHTW-60 (412.4 mg), C-306 (356.3) followed by WH-1105 (259.9 mg) had maximum peduncle dry weight under timely sown condition and genotypes. Genotypes DHTW-60 (380.6 mg), C-306 (330.3 mg) followed by HD-2967 (289.3 mg) under late sown and genotypes DHTW-60 (244.3 mg), C-306 (219.7 mg) followed by HTW-11 (201.7 mg) and HD-2967 (192.1 mg) under very late sown was found to have maximum in peduncle dry weight under different drought conditions. Genotype KUNDAN under timely and late sown whereas, genotype AKAW-3717 showed minimum average peduncle dry weight among all genotypes under all drought and delayed sowing conditions.

4.4.3.1 Penultimate internode length (cm)

Data in Table 40 represented reduction in penultimate internode length (cm) in all genotypes along with drought application and delayed sowing condition. Application of drought at different vegetative growth period reduced the penultimate internode length in timely, late and very late sown conditions and maximum reduction in penultimate internode length was found at D40+D65 and under complete drought situation under late (10.3 and 19.5 cm) and very late sown (17.7 and 16.4 cm) whereas minimum reduction was observed under timely sown condition (20.2 and 18.9 cm).

Average penultimate internode length for different drought stress condition ranged from 18.9 to 23.1 cm (timely sown), 16.4 to 21.5 cm (late sown) and 10.3 to 19.5 cm (very late sown). Maximum average penultimate internode length observed at timely sown (20.9 cm) whereas, combination of late (18.8 cm) and very late sown (14.9 cm) condition showed maximum reduction in mean penultimate internode length.

Table 39: Response of wheat genotypes to drought and high temperature for peduncle dry weight (mg) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	290.3	283.7	276.7	271.0	264.3	**277.2**	286.7	276.7	266.7	259.0	248.0	**267.4**	169.7	150.3	136.0	86.3	73.7	**123.2**
C-306	404.0	375.0	356.0	332.7	314.0	**356.3**	349.7	341.7	336.3	327.3	296.3	**330.3**	334.0	240.7	223.7	154.7	145.3	**219.7**
DHTW-60	450.7	429.7	406.0	396.7	378.7	**412.4**	419.0	393.3	376.3	367.3	347.3	**380.6**	327.7	288.0	238.0	190.3	177.3	**244.3**
HD-2967	236.0	226.3	222.7	216.0	214.7	**223.1**	328.3	295.3	289.3	275.3	258.3	**289.3**	280.7	223.3	197.0	135.7	124.0	**192.1**
HTW-11	360.0	325.3	301.3	283.3	274.7	**308.9**	214.0	210.3	205.0	203.7	197.0	**206.0**	291.0	227.0	208.3	143.7	138.3	**201.7**
KUNDAN	228.7	221.0	217.7	210.7	198.0	**215.2**	206.3	200.0	196.0	191.3	181.3	**195.0**	197.0	170.7	153.3	95.3	87.7	**140.8**
WH-730	242.3	229.7	224.3	222.3	216.3	**227.0**	214.7	209.0	201.3	201.0	194.0	**204.0**	189.7	172.7	154.3	95.7	81.0	**138.7**
WH-1105	328.7	308.7	288.3	282.0	272.0	**295.9**	278.0	264.3	258.0	251.3	240.3	**258.4**	248.7	216.3	193.0	123.7	115.3	**179.4**
Mean (D)	**317.6**	**299.9**	**286.6**	**276.8**	**266.6**	**289.5**	**287.1**	**273.8**	**266.1**	**259.5**	**245.3**	**266.4**	**254.8**	**211.1**	**188.0**	**128.2**	**117.8**	**180.0**
CD at 5%	**D= 2.34, G= 2.96, DxG= 6.61**						**D= 2.83, G= 3.58, DxG= 8.02**						**D= 3.33, G= 4.21, DxG= 9.42**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 40: Response of wheat genotypes to drought and high temperature for penultimate internode length (cm) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	30.5	29.2	27.5	26.3	24.4	**27.6**	28.4	25.6	24.9	23.5	21.8	**24.8**	24.2	21.8	18.8	13.2	12.4	**18.1**
C-306	25.7	22.2	21.2	20.7	19.7	**21.9**	22.5	21.7	20.1	18.9	17.7	**20.2**	21.5	19.9	18.0	12.5	11.5	**16.7**
DHTW-60	35.7	33.4	32.7	31.0	28.5	**32.3**	33.2	30.0	27.0	25.7	24.3	**28.0**	29.0	26.0	22.2	17.1	16.8	**22.2**
HD-2967	19.3	18.6	18.5	17.8	16.7	**18.2**	18.7	17.6	16.5	15.9	15.6	**16.9**	18.3	16.3	14.1	10.2	9.4	**13.7**
HTW-11	16.1	15.0	14.6	13.9	13.2	**14.6**	15.4	13.7	13.2	12.4	11.4	**13.2**	13.0	11.5	10.7	6.5	5.4	**9.4**
KUNDAN	17.5	16.8	16.2	15.6	14.5	**16.1**	16.6	16.0	14.7	13.9	12.0	**14.6**	14.2	13.2	12.4	8.3	7.7	**11.2**
WH-730	18.6	17.5	17.2	17.0	16.2	**17.3**	17.5	15.7	14.9	13.9	12.4	**14.9**	16.3	15.5	13.7	9.5	8.2	**12.6**
WH-1105	21.0	19.5	19.1	19.0	18.2	**19.4**	19.5	18.5	17.9	17.0	16.2	**17.8**	19.7	19.2	17.4	11.4	10.9	**15.7**
Mean (D)	**23.1**	**21.5**	**20.9**	**20.2**	**18.9**	**20.9**	**21.5**	**19.9**	**18.7**	**17.7**	**16.4**	**18.8**	**19.5**	**17.9**	**15.9**	**11.1**	**10.3**	**14.9**
CD at 5%	**D= 0.32, G= 0.40, DxG= 0.90**						**D= 0.44, G= 0.55 DxG= 1.24**						**D= 0.47, G= 1.03, DxG= 1.32**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Significant difference was found for penultimate internode length in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sowing condition.

Average penultimate internode length for genotypes ranged from 14.6 to 32.3 cm (timely sown), 13.2 to 28.0 cm (late sown) and 9.4 to 22.2 cm (very late sown). Genotype DHTW-60 (32.3, 28.0 and 22.2 cm) and AKAW-3717 (27.6, 24.8 and 18.1 cm) followed by C-306 (21.9, 20.2 and 16.7 cm) had maximum penultimate internode length under timely, late and very late sown condition respectively. Maximum penultimate internode length was found in genotypes HTW-11 among all genotypes under all drought and delayed sowing conditions.

4.4.3.2 Penultimate internode dry weight (mg)

Penultimate internode dry weight (mg) presented in Table 41 showed reduction in dry weight in all genotypes under drought application and delayed sowing condition. Different drought application showed reduction in penultimate internode dry weight in all (timely, late and very late) sown conditions. Maximum reduction in penultimate internode dry weight was found at D40+D65 and complete drought situation under late (176.7 and 164.5 mg) and very late sown (111.2 and 103.2 mg) whereas, minimum reduction was observed under timely sown condition (202.1 and 189.4 mg).

Average penultimate internode dry weight for different drought stress condition ranged from 189.4 to 231.6 mg (timely sown), 164.5 to 215.7 mg (late sown) and 103.2 to 195.3 mg (very late sown). Maximum average penultimate internode dry weight observed at timely sown (209.8 mg) whereas, combination of late (188.4 mg) and very late sown (149.3 mg) condition showed maximum reduction in mean penultimate internode dry weight.

Significant difference was found for penultimate internode dry weight in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition.

Average penultimate internode dry weight for genotypes ranged from 142.4 to 377.7 mg (timely sown), 129.2 to 328.6 mg (late sown) and 92.1 to 260.2 mg (very late sown). Genotype DHTW-60 (377.7 and 328.6 mg) and C-306 (308.4 and 277.5 mg) followed by HTW-11 (219.9 and 202.7 mg) had maximum penultimate internode dry weight under timely and late sown condition respectively whereas, genotypes DHTW-60 (260.2 mg), C-306 (202.7 mg) followed by HD-2967 (167.7 mg) under very late sown environment were found maximum in penultimate internode dry weight under different drought conditions. Genotype KUNDAN under timely and late sown whereas, genotype AKAW-3717 showed minimum average penultimate internode dry weight among all genotypes under all drought and delayed sowing conditions.

Table 41: Response of wheat genotypes to drought and high temperature for penultimate internode dry weight (g) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	178.3	166.0	162.0	161.0	154.7	**164.4**	166.0	156.7	152.0	144.7	137.3	**151.3**	167.7	162.7	148.0	97.3	92.7	**133.7**
C-306	341.3	326.0	307.3	294.3	273.0	**308.4**	317.0	286.0	278.3	262.7	243.7	**277.5**	271.0	244.3	211.0	148.3	138.7	**202.7**
DHTW-60	417.7	390.7	383.0	363.0	334.3	**377.7**	389.3	351.0	316.3	301.3	285.0	**328.6**	339.7	304.3	259.7	200.3	197.0	**260.2**
HD-2967	168.3	158.0	155.3	154.0	146.0	**156.3**	158.0	142.0	134.7	125.7	112.3	**134.5**	216.0	199.7	181.3	126.0	115.7	**167.7**
HTW-11	258.3	222.7	213.3	207.7	197.7	**219.9**	226.0	218.0	201.7	189.7	178.0	**202.7**	147.0	139.7	123.7	86.0	74.3	**114.1**
KUNDAN	157.3	147.0	143.0	136.0	128.7	**142.4**	150.7	133.7	128.7	121.3	111.7	**129.2**	127.0	112.3	104.7	63.7	53.0	**92.1**
WH-730	178.3	171.7	171.0	164.3	153.7	**167.8**	172.3	162.0	151.7	146.3	143.0	**155.1**	168.7	150.3	130.3	94.7	86.7	**126.1**
WH-1105	153.3	147.7	141.7	136.7	127.3	**141.3**	146.0	140.3	128.7	121.7	105.0	**128.3**	125.0	115.3	108.7	73.0	67.7	**97.9**
Mean (D)	**231.6**	**216.2**	**209.6**	**202.1**	**189.4**	**209.8**	**215.7**	**198.7**	**186.5**	**176.7**	**164.5**	**188.4**	**195.3**	**178.6**	**158.4**	**111.2**	**103.2**	**149.3**
CD at 5%	**D= 3.34, G= 4.23, DxG= 9.45**						**D= 4.31, G= 5.45, DxG= 12.19**						**D= 5.62, G= 6.21, DxG= 14.78**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 42: Response of wheat genotypes to drought and high temperature for grain filling duration under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	35.0	36.0	33.7	29.3	27.6	**32.3**	29.0	28.0	27.7	24.3	21.6	**26.1**	20.7	21.7	20.1	16.0	15.3	**18.8**
C-306	39.7	37.0	37.0	31.0	29.6	**34.9**	30.3	29.0	30.0	24.0	21.3	**26.9**	23.0	20.9	19.7	19.0	18.1	**20.1**
DHTW-60	43.0	41.3	38.7	33.0	30.9	**37.4**	41.0	36.4	36.0	32.3	30.3	**35.2**	39.3	35.3	34.5	33.0	31.0	**34.6**
HD-2967	44.6	44.3	41.0	36.0	33.6	**39.9**	38.7	36.4	35.0	30.0	27.6	**33.5**	35.0	32.2	29.3	27.7	25.5	**29.9**
HTW-11	36.3	37.0	36.0	30.0	27.3	**33.3**	35.4	33.4	32.7	27.0	24.9	**30.7**	31.3	28.1	25.3	24.0	22.9	**26.3**
KUNDAN	41.3	41.0	35.3	30.7	27.6	**35.2**	33.7	29.0	27.0	25.0	23.6	**27.7**	28.7	26.4	23.5	21.3	20.4	**24.1**
WH-730	36.0	35.7	34.0	30.7	27.9	**32.9**	30.0	27.7	26.9	22.7	22.0	**25.9**	24.7	23.0	20.4	19.7	18.8	**21.3**
WH-1105	47.0	44.3	42.0	38.3	36.3	**41.6**	37.0	33.0	29.3	24.7	21.6	**29.1**	30.3	29.0	22.2	20.3	19.3	**24.2**
Mean (D)	**40.4**	**39.6**	**37.2**	**32.4**	**30.1**	**35.9**	**34.4**	**31.6**	**30.6**	**26.3**	**24.1**	**29.4**	**29.1**	**27.1**	**24.4**	**22.6**	**21.4**	**24.9**
CD at 5%	**D= 0.50, G= 0.66, DxG= 1.42**						**D= 0.48, G= 0.61, DxG= 1.40**						**D= 0.41, G= 0.18, DxG= 0.41**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

4.4.4 Grain growth rate (GGR, mg/day)

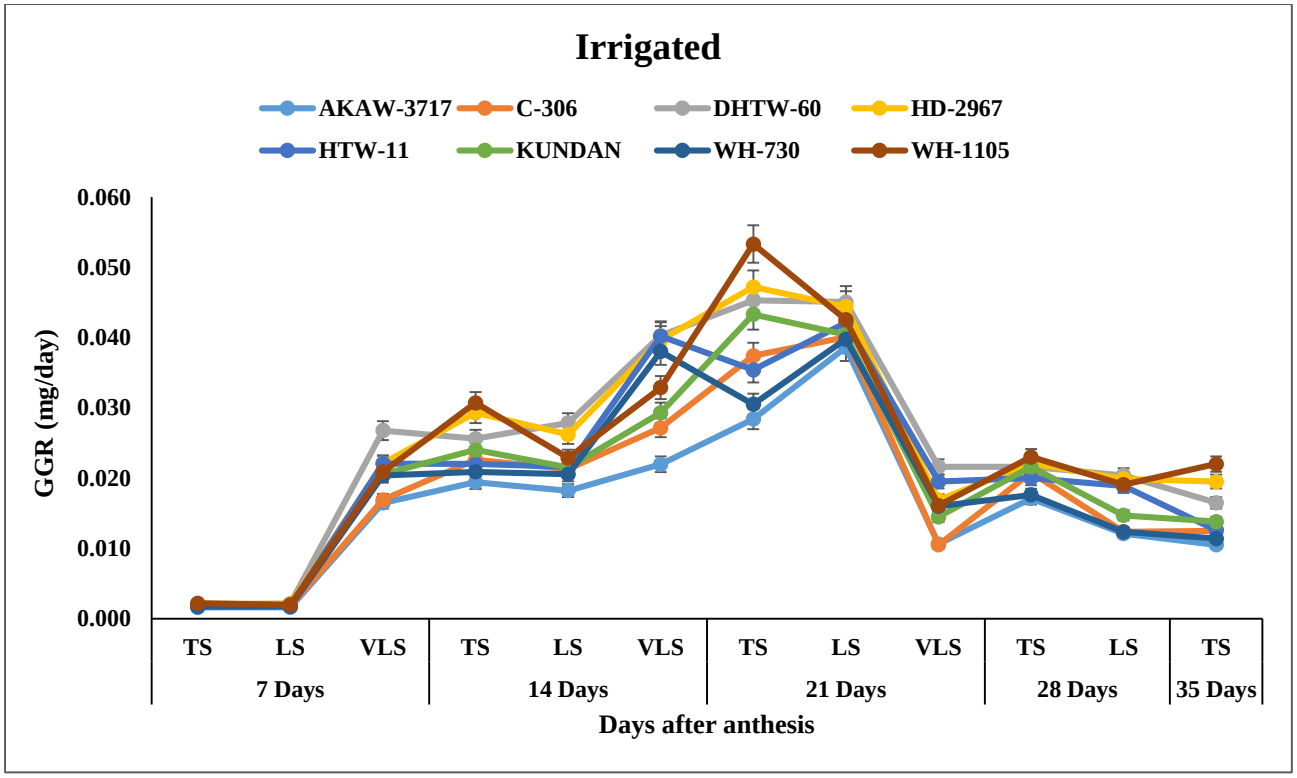
Graphical representation in Figure 35 (irrigated), Figure 36 (D40), Figure 37 (D65), Figure 38 (D40+D65), and Figure 39 (Complete drought) showed data grain growth rate (GGR) at 7, 14, 21, 28 and 35 days after anthesis under timely, late and very late sown condition. Normal irrigated and drought situation *i.e.* drought at 40 DAS and drought at 65 DAS showed grain growth period between 7 to 35 days under timely sown, 7 to 28 days under late sown and 7 to 21 days for very late sown condition whereas, drought condition D40+D65 and complete drought indicate reduction in grain growth period and ranged between 7 to 28 days (timely sown), 7 to 21 days (late sown) and 7 to 14 days (very late sown).

Maximum grain weight accumulation was observed between 14 to 28 days after anthesis (DAA, timely sown), 14 to 21 DAA (late sown) and 7 to 21 DAA under irrigated and drought situation D40 and D65, but in drought situation D40+D65 and complete drought maximum dry matter accumulated between 14 to 21 (timely sown) and 7 to 14 days after anthesis under late and very late sown conditions.

Significant reduction in average grain growth rate for genotypes found at D40+D65 & complete drought and grain growth rate under controlled (irrigated) condition ranged between 0.015 to 0.026 mg/day (timely sown), 0.018 to 0.024 mg/day (late sown) and 0.016 to 0.030 mg/day (very late sown) condition. For drought situation drought at 40 days after sowing it varied between 0.016 to 0.026 mg/day (timely sown), 0.011 to 0.015 mg/day (late sown) and 0.013 to 0.026 mg/day (very late sown) and drought at 65 days after sowing showed range between 0.015 to 0.023 mg /day (timely sown), 0.012 to 0.020 mg/day (late sown) and 0.011 to 0.024 mg/day (very late sown). Combined drought at different growth stage (drought 40 days after sowing and drought 65 days after sowing) showed decrease in GGR for genotype fluctuated from 0.013 to 0.022 mg/day (timely sown), 0.014 to 0.026 mg/day (late sown) and 0.012 to 0.025 mg/day (very late sown) whereas, complete drought showed maximum reduction in days for grain growth period and grain growth rate that was ranges from 0.010 to 0.021 mg/day (timely sown), 0.012 to 0.020 mg/day (late sown) and 0.007 to 0.019 mg/day under very late sown condition. Genotype AKAW-3717 showed minimum average grain growth rate among all genotypes under all drought and delayed sowing conditions.

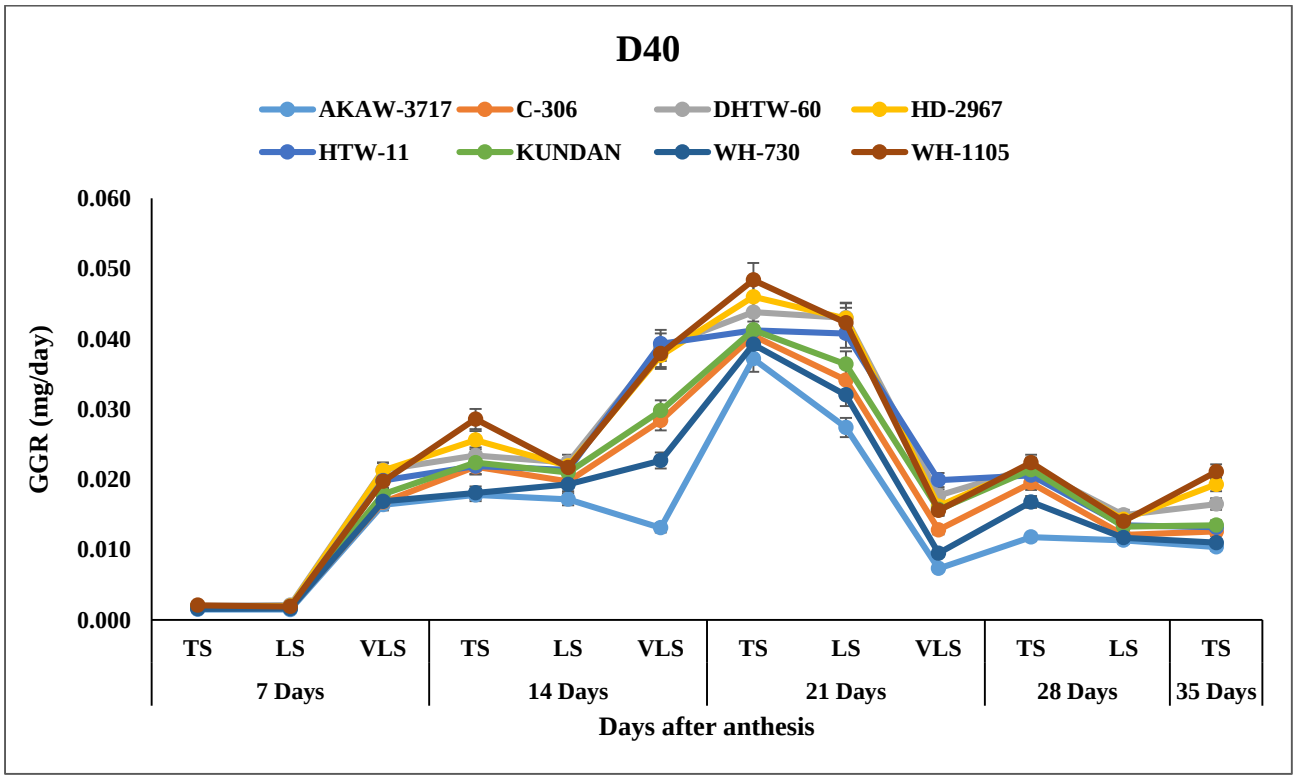
4.4.5 Grain filling duration

Grain filling duration (GFD) presented in Table 42 showed reduction in days to grain filling duration in all genotypes under different application of drought with delayed sowing condition. Different drought application showed reduction in duration of grain filling in all (timely, late and very late) sown conditions. Minimum days to grain filling observed at D40+D65 and complete drought situation under late (26.3 and 24.1) and very late sown (22.6 and 21.4) whereas, maximum days to grain filling was observed under timely sown irrigate and D40 drought condition (40.4 and 39.0).



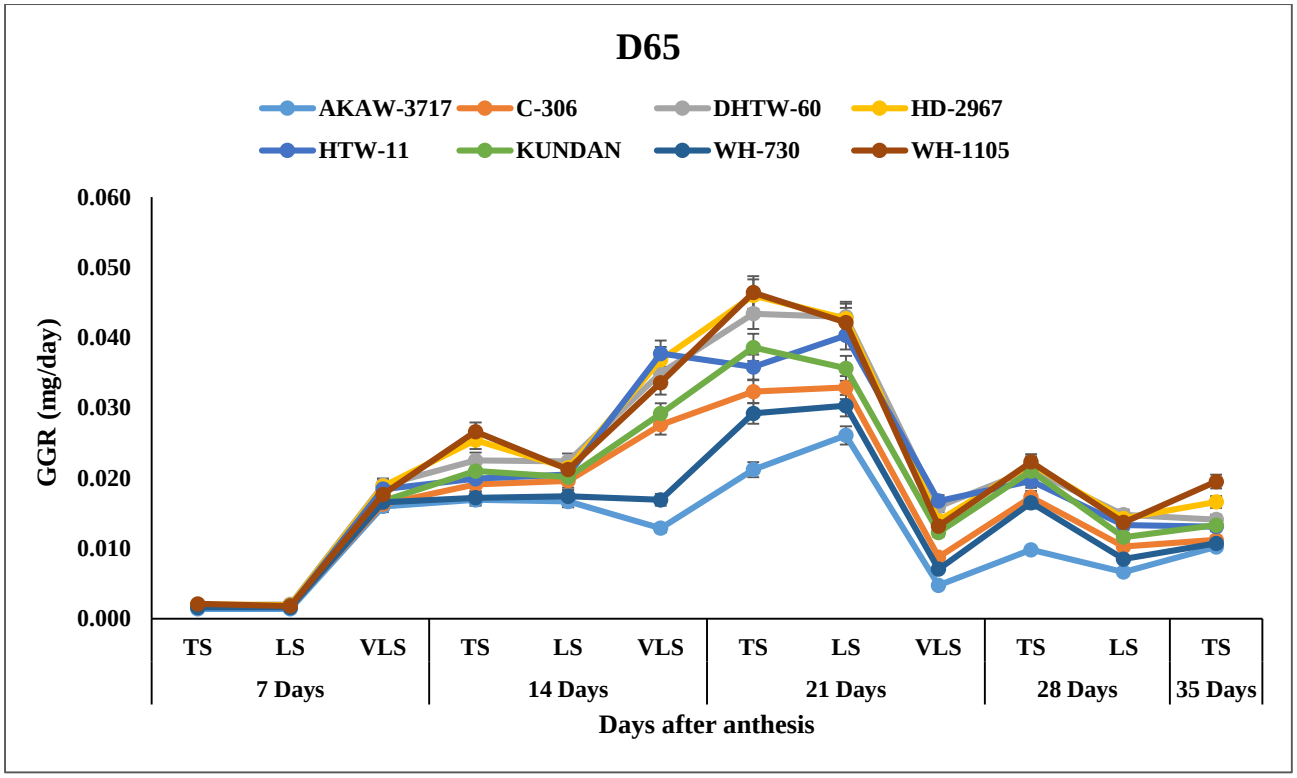
TS- Timely sown, **LS-** Late sown, **VLS-** very late sown, **GGR-** Grain growth rate

Fig. 35: Grain growth rate (GGR, mg/day) of wheat genotypes at different days after anthesis under timely, late and very late sown irrigated conditions



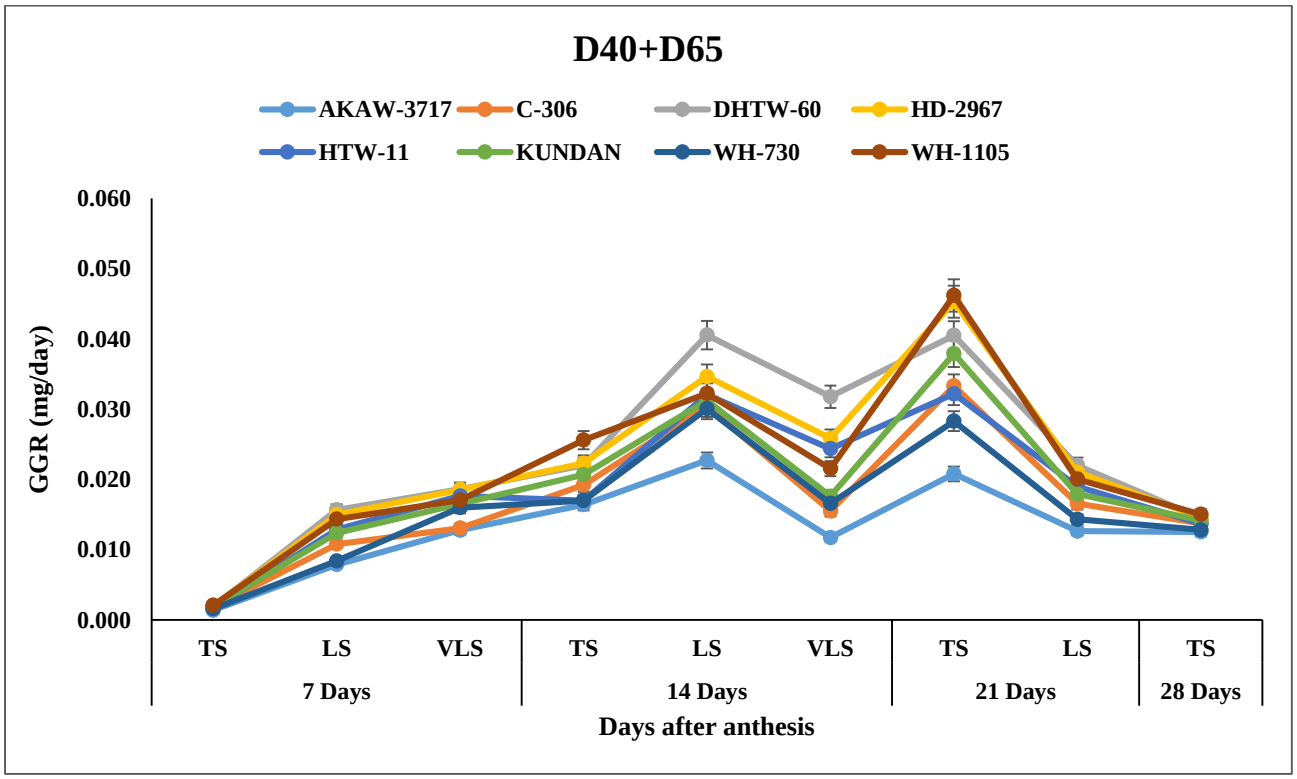
TS- Timely sown, **LS-** Late sown, **VLS-** very late sown, **GGR-** Grain growth rate

Fig. 36: Response of drought at 40 days after sowing (DAS) on grain growth rate (GGR, mg/day) of wheat genotypes at different days after anthesis under timely, late and very late sown conditions



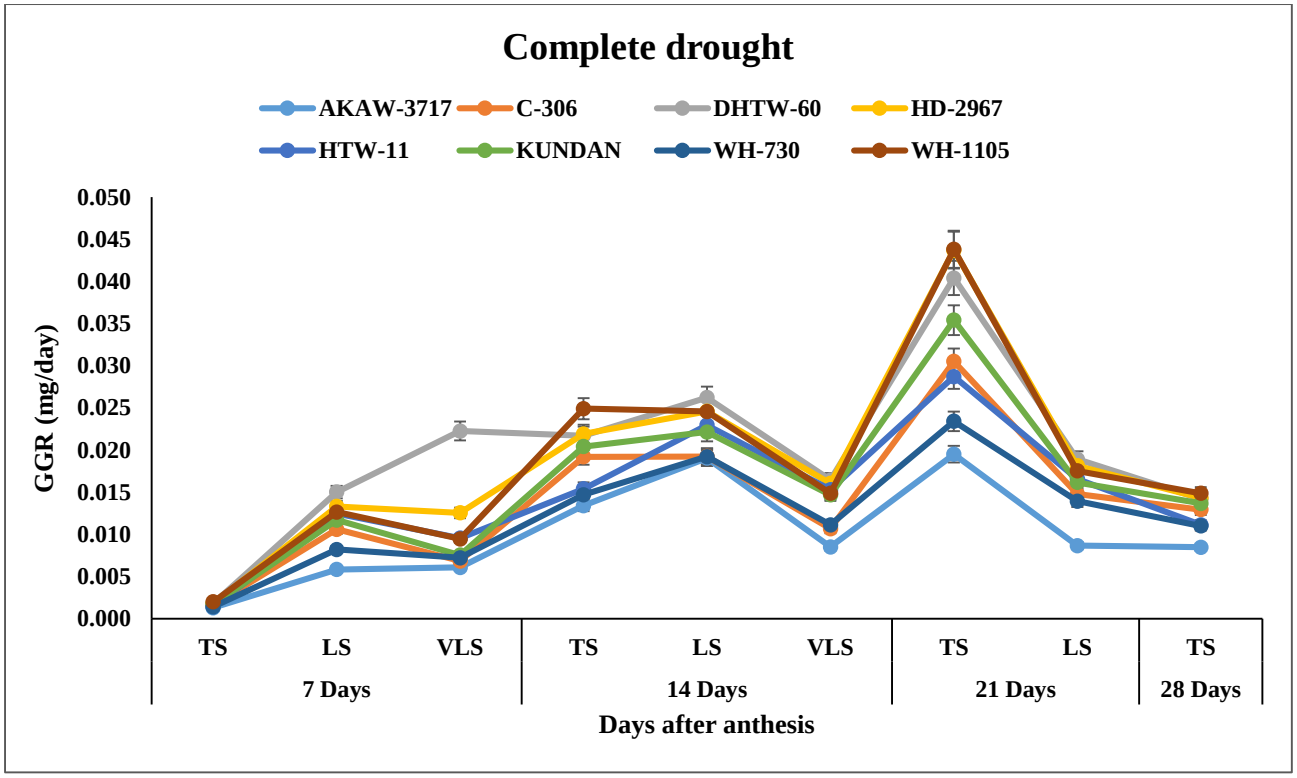
TS- Timely sown, **LS-** Late sown, **VLS-** very late sown, **GGR-** Grain growth rate

Fig. 37: Response of drought at 65 days after sowing (DAS) on grain growth rate (GGR, mg/day) of wheat genotypes at different days after anthesis under timely, late and very late sown conditions



TS- Timely sown, **LS-** Late sown, **VLS-** very late sown, **GGR-** Grain growth rate

Fig. 38: Response of drought at 40+65 days after sowing (DAS) on grain growth rate (GGR, mg/day) of wheat genotypes at different days after anthesis under timely, late and very late sown conditions



TS- Timely sown, **LS-** Late sown, **VLS-** very late sown, **GGR-** Grain growth rate

Fig. 39: Response of complete drought on grain growth rate (GGR, mg/day) of wheat genotypes at different days after anthesis under timely, late and very late sown conditions

Average grain filling duration for different drought stress condition ranged from 30.1 to 40.4 (timely sown), 24.1 to 34.4 (late sown) and 21.4 to 29.1 (very late sown). Maximum average grain filling duration observed at timely sown (35.9) whereas, combination of late (29.4) and very late sown (25.0) condition showed maximum reduction in mean grain filling duration. Significant difference was found for grain filling duration in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition.

Average grain filling duration for genotypes ranged from 32.3 to 39.9 (timely sown), 26.1 to 35.2 (late sown) and 18.8 to 35.4 (very late sown). Genotype WH-1105 (41.6) followed by HD-2967 (39.0) showed maximum days to grain filling (41.6 and 39.0) respectively, under timely sown condition whereas, genotype DHTW-60 (35.2 and 34.6) and HD-2967 (33.5 and 29.2) followed by HTW-11 (30.7 and 26.3) had maximum grain filling duration under late and very late sown with different drought situation. Genotype AKAW-3717 showed minimum average grain filling duration among all genotypes under all drought and delayed sowing conditions.

4.4.6 Number of spikelets per spike

Data present in Table 43 showed number of spikelets per spike under different drought application with delayed sowing condition. Drought application reduced in the spikelets per spike under timely, late and very late sown conditions and maximum number of spikelets per spike were found in control (irrigated) condition (19.9) under timely sown condition and minimum days to physiological maturity were observed in compete drought stress (17.6) under very late sown condition.

Average number of spikelets per spike for different drought stress condition ranged from 18.6 to 19.9 (timely sown), 18.2 to 19.5 (late sown) and 17.6 to 18.9 (very late sown). Maximum number of spikelets per spike observed at timely sown (19.2) whereas, combination of late (18.8) and very late sown (18.3) condition showed reduction in mean number of spikelets per spike. Significant difference was found for number of spikelets per spike in all genotypes and different drought stress condition whereas, interaction effects was not significant for genotypes and different drought condition.

Average number of spikelets per spike for genotypes ranged from 17.0 to 20.8 (timely sown), 16.8 to 19.8 (late sown) and 16.5 to 19.5 (very late sown). Genotype WH-1105 (20.8) followed by HD-2967 (20.3) had maximum number of spikelets per spike under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (19.8) followed byHD-2967 (19.7) and WH-1105 (19.7) had maximum number of spikelets per spike under late sown condition and genotypes DHTW-60 (19.5) followed by HD-2967 (19.3) and HTW-11 (19.3) under very late sown condition. Genotype AKAW-3717 showed minimum number of spikelets per spike among all genotypes under all drought and delayed sowing conditions.

4.4.7 Spike length (cm)

Table 44 showed reduction in spike length along with time of drought application and delayed sowing condition among all genotypes. Application of drought reduced the spike length in timely, late and very late sown conditions and minimum spike length was found at D40+D65 and complete drought situation under late (9.8 and 9.4 cm) and very late sown (9.4 and 8.4 cm) whereas, maximum spike length was observed under timely sown condition (12.6 and 10.2 cm).

Average spike length for different drought stress condition ranged from 10.2 to 12.6 cm (timely sown), 9.4 to 11.6 cm (late sown) and 8.4 to 11.1 cm (very late sown). Maximum average spike length observed at timely sown (11.3 cm) whereas, combination of late (10.4 cm) and very late sown (9.9 cm) condition showed maximum reduction in mean spike length. Significant difference was found for spike length in all genotypes and different drought stress condition. No significant interaction effects were found between genotypes and different drought condition with delayed sown condition.

Table 43: Response of wheat genotypes to drought and high temperature for number of spikelets per spike under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	17.3	17.1	17.2	16.7	16.5	**17.0**	17.2	17.0	16.9	16.7	16.3	**16.8**	17.1	16.7	16.3	16.3	15.9	**16.5**
C-306	20.1	19.3	18.7	18.8	18.6	**19.1**	19.0	18.6	18.8	18.3	18.0	**18.5**	17.6	17.5	16.8	16.6	16.4	**17.0**
DHTW-60	20.9	20.3	19.8	19.9	19.7	**20.1**	20.4	20.0	19.7	19.4	19.6	**19.8**	20.2	20.0	19.5	19.2	18.8	**19.5**
HD-2967	20.9	20.6	20.3	20.1	19.7	**20.3**	20.7	20.1	19.7	19.1	18.9	**19.7**	20.1	19.6	19.2	19.0	18.3	**19.3**
HTW-11	19.5	19.3	18.6	18.4	18.0	**18.8**	19.8	19.6	18.9	18.8	18.6	**19.1**	19.9	19.8	19.4	18.9	18.4	**19.3**
KUNDAN	20.2	20.0	19.0	18.9	18.7	**19.4**	19.4	19.1	18.6	18.6	18.3	**18.8**	18.7	18.5	18.1	17.9	17.9	**18.2**
WH-730	18.7	18.3	17.8	17.0	17.0	**17.8**	18.8	18.1	17.5	17.2	17.0	**17.7**	18.1	17.8	17.3	17.3	16.7	**17.4**
WH-1105	21.8	21.1	20.6	20.3	20.3	**20.8**	20.4	20.1	19.7	19.4	19.1	**19.7**	19.3	19.0	18.5	18.7	18.4	**18.8**
Mean (D)	**19.9**	**19.5**	**19.0**	**18.8**	**18.6**	**19.2**	**19.5**	**19.1**	**18.7**	**18.4**	**18.2**	**18.8**	**18.9**	**18.6**	**18.2**	**18.0**	**17.6**	**18.3**
CD at 5%	**D= 0.30, G= 0.51, DxG= NS**						**D= 0.31, G= 0.50, DxG= NS**						**D= 0.34, G= 0.64, DxG= NS**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 44: Response of wheat genotypes to drought and high temperature for spike length (cm) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	11.0	10.5	9.2	8.9	8.3	**9.6**	10.2	9.5	9.1	9.0	8.5	**9.3**	9.8	9.1	8.5	7.8	6.9	**8.4**
C-306	12.5	11.9	10.7	10.1	10.0	**11.0**	11.0	10.5	9.7	9.2	8.9	**9.9**	10.1	9.8	9.5	8.9	7.5	**9.2**
DHTW-60	13.3	12.3	11.9	11.3	10.9	**11.9**	12.9	12.1	11.7	10.9	10.5	**11.6**	12.3	11.6	11.3	10.5	9.7	**11.1**
HD-2967	13.2	12.8	12.5	11.9	10.9	**12.3**	12.5	11.5	11.2	10.0	9.7	**11.0**	12.0	11.4	10.9	10.4	8.9	**10.7**
HTW-11	12.1	11.6	10.6	10.1	9.8	**10.8**	11.7	10.8	10.7	10.1	9.8	**10.6**	11.8	11.2	10.9	9.6	8.5	**10.4**
KUNDAN	12.6	12.0	11.5	10.7	10.2	**11.4**	11.5	10.8	10.3	9.7	9.1	**10.3**	11.0	10.1	9.7	9.3	8.4	**9.7**
WH-730	11.6	11.2	10.5	10.0	9.6	**10.6**	10.3	10.2	9.3	9.1	8.9	**9.6**	10.4	9.9	9.5	9.0	8.4	**9.4**
WH-1105	14.4	14.1	12.8	12.5	11.6	**13.1**	12.3	11.0	10.7	10.1	9.8	**10.8**	11.4	10.5	9.9	9.4	8.5	**9.9**
Mean (D)	**12.6**	**12.1**	**11.2**	**10.7**	**10.2**	**11.3**	**11.6**	**10.8**	**10.3**	**9.8**	**9.4**	**10.4**	**11.1**	**10.5**	**10.0**	**9.4**	**8.4**	**9.9**
CD at 5%	**D= 0.41, G= 0.42, DxG= NS**						**D= 0.35, G= 0.44, DxG= NS**						**D= 0.34, G= 0.46, DxG= NS**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Average spike length for genotypes ranged from 9.6 to 13.1 cm (timely sown), 9.3 to 11.6 cm (late sown) and 8.4 to 11.1 cm (very late sown). Genotype WH-1105 (13.1 cm) followed by HD-2967 (12.3 cm) had maximum number of spikelets per spike under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (11.6 cm) followed by HD-2967 (11.0 cm) had maximum number of spikelets per spike under late sown condition and genotypes DHTW-60 (11.1 cm) and HD-2967 (10.7 cm) followed by HTW-11 (10.4 cm) under very late sown condition. Genotype AKAW-3717 showed minimum in mean spike length among all genotypes under all drought and delayed sowing conditions.

4.4.8 Number of productivity tillers per square meter

Data in Table 45 indicate reduction in number of productivity tillers per square meter under drought and delayed sowing condition among all genotypes. Application of drought reduced the number of productivity tillers per meter square in timely, late and very late sown conditions and minimum number of productivity tillers per meter square was found at complete drought situation under very late sown (165.8) whereas, maximum number of productivity tillers per meter square was observed under timely sown condition (375.9).

Average number of productivity tillers per meter square for different drought stress condition ranged from 262.6 to 375.9 (timely sown), 240.5 to 336.8 (late sown) and 165.8 to 254.8 (very late sown). Maximum average number of productivity tillers per meter square observed at timely sown (321.5) whereas, combination of late (287.8) and very late sown (209.0) condition showed minimum number of productivity tillers per meter square. Significant difference was found for number of productivity tillers per meter square in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition.

Average Number of productivity tillers per meter square for genotypes ranged from 231.8 to 421.6 (timely sown), 202.0 to 374.6 (late sown) and 167.4 to 263.9 (very late sown). Genotype WH-1105 (421.6) followed by HD-2967 (395.9) had maximum number of spikelets per spike under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (374.6), HD-2967 (343.1) followed by WH-1105 (317.4) had maximum number of spikelets per spike under late sown condition and genotypes DHTW-60 (263.9) and HD-2967 (236.3) followed by HTW-11 (225.9) under very late sown condition. Genotype AKAW-3717 showed minimum in mean number of productivity tillers per meter square among all genotypes under all drought and delayed sowing conditions.

4.4.9 Biomass per square meter (g)

Drought and delayed sowing condition showed reduction in plant biomass square per meter are presented in Table 46. Drought application at different growth stages reduced the biomass per square meter in timely, late and very late sown conditions and minimum biomass per square meter was observer at complete drought situation under very late sown (200.8 g),

followed by late sown drought condition (414.0 g) whereas, maximum biomass per square meter was observed under timely sown irrigated condition (1549.0 g).

Average biomass per square meter for different drought stress condition ranged from 958.8 to 1549.0 g (timely sown), 414.9 to 1073.0 g (late sown) and 200.8 to 631.9 g (very late sown). Maximum average biomass per square meter observed at timely sown (1246.6 g) whereas, combination of late (717.9 g) and very late sown (415.50 g) condition showed minimum number of productivity tillers per meter square. Significant difference was found for biomass per square meter in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sown condition.

Average biomass per square meter for genotypes ranged from 1143.9 to 1353.3 g (timely sown), 775.7 to 1311.6 g (late sown) and 754.2 to 1280.9 g (very late sown). Genotype WH-1105 (1353.3 g) followed by HD-2967 (1311.6 g) had maximum n biomass per square meter under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (824.7 g), HD-2967 (775.7 g) followed by WH-1105 (754.2 g) had maximum biomass per square meter under late sown condition and genotypes DHTW-60 (474.1 g) and HD-2967 (447.9 g) followed by HTW-11 (429.6 g) under very late sown condition. Genotype AKAW-3717 showed maximum reduction in mean biomass per square meter among all genotypes under all drought and delayed sowing conditions.

4.5.0 Number of grain per spike

The significant reduction in number of grains per spike in all genotypes along with time of drought application and delayed sowing condition are shown in Table 47. Drought application reduced the number of grains per spike in late and very late sown conditions and maximum number of grains per spike were found in control (irrigated) condition (53.1) under timely sown condition and minimum number of grains per spike were observed in compete drought stress (42.8) under very late sown condition.

Average number of grains per spike for different drought stress condition varied from 46.2 to 53.1 (timely sown), 45.2 to 53.1 (late sown) and 42.8 to 49.3 (very late sown). The drought situation of D40+D65, and complete drought resulted significant reduction in number of grains per spike (48.0 and 46.2) under timely sown and (44.1 and 42.8) under very late sown condition, however under late own condition significant reduction for early heading was observed in D65, D40+D65 and complete drought condition only (48.3, 46.8 and 45.2).

Significant difference was found in all genotypes and different drought stress condition whereas, no significant difference was observed among drought and genotypes interaction under timely sown and late sown condition but very late sown condition showed significant interaction effect for drought and genotypes.

Table 45: Response of wheat genotypes to drought and high temperature for number of productivity tillers per square meter under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	283.6	271.8	224.4	193.8	185.4	**231.8**	259.8	230.0	200.9	165.4	153.7	**202.0**	215.4	190.1	162.1	141.8	127.4	**167.4**
C-306	354.5	330.9	295.4	248.3	248.2	**295.4**	312.4	287.3	249.6	230.4	207.8	**257.5**	228.1	218.0	172.4	156.0	141.8	**183.2**
DHTW-60	401.8	401.8	354.5	342.7	295.4	**359.2**	421.7	398.7	371.5	347.9	333.1	**374.6**	329.7	317.0	233.2	226.9	212.9	**263.9**
HD-2967	454.9	437.2	413.6	354.5	319.2	**395.9**	385.1	371.5	336.1	325.0	297.7	**343.1**	291.5	259.7	233.0	212.9	184.6	**236.3**
HTW-11	342.7	319.2	283.6	236.2	225.7	**281.5**	346.3	314.7	297.7	282.8	257.7	**299.8**	266.1	253.6	223.1	198.5	184.6	**225.2**
KUNDAN	378.1	354.5	319.1	295.4	271.8	**323.8**	318.3	299.9	282.8	242.9	222.3	**273.2**	234.4	228.1	202.8	170.2	156.0	**198.3**
WH-730	307.2	295.4	271.8	228.0	212.8	**263.1**	287.0	260.0	224.5	212.6	189.1	**234.6**	228.3	215.6	192.8	170.2	149.1	**191.2**
WH-1105	484.5	477.4	437.2	366.3	342.7	**421.6**	363.8	354.5	304.4	302.0	262.2	**317.4**	240.8	240.8	223.1	191.6	170.4	**213.3**
Mean (D)	**375.9**	**361.0**	**324.9**	**283.2**	**262.6**	**321.5**	**336.8**	**314.6**	**283.4**	**263.6**	**240.5**	**287.8**	**254.3**	**240.4**	**205.3**	**183.5**	**165.8**	**209.9**
CD at 5%	**D= 4.78, G= 6.04, DxG= 13.52**						**D= 4.49, G= 5.69, DxG= 12.72**						**D= 4.81, G= 6.67, DxG= 5.97**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 46: Response of wheat genotypes to drought and high temperature for biomass per square meter (g) under timely, late and very late sown conditions

Genotypes	Timely Sown						Late Sown						Very Late Sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+65	DR			D40	D65	D40+65	DR			D40	D65	D40+65	DR	
AKAW 3717	1413.0	1259.8	1197.3	1141.3	708.2	**1143.9**	940.2	752.7	621.2	550.5	238.0	**620.5**	570.7	481.5	379.9	281.5	150.0	**372.7**
C-306	1503.8	1313.6	1222.8	1150.5	978.3	**1233.8**	1020.1	767.9	622.3	589.1	353.3	**670.5**	594.0	485.3	384.8	289.7	157.1	**382.2**
DHTW-60	1576.1	1358.7	1250.0	1177.7	1041.8	**1280.9**	1313.6	911.4	751.6	616.8	529.9	**824.7**	729.9	538.0	465.2	375.5	262.0	**474.1**
HD-2967	1666.8	1376.6	1259.2	1186.4	1069.0	**1311.6**	1121.2	897.8	713.6	615.8	529.9	**775.7**	671.7	523.4	449.5	355.4	239.7	**447.9**
HTW-11	1467.4	1304.3	1222.8	1150.5	933.2	**1215.7**	1063.6	870.1	677.7	607.6	463.6	**736.5**	638.6	514.7	420.1	342.9	231.5	**429.6**
KUNDAN	1531.0	1340.8	1222.8	1177.7	1005.4	**1255.5**	1032.6	842.4	665.8	594.0	436.4	**714.2**	618.5	499.5	406.0	303.3	193.5	**404.1**
WH-730	1422.3	1277.2	1210.3	1141.3	838.0	**1177.8**	987.5	759.2	621.2	581.5	282.6	**646.4**	607.1	495.7	394.0	297.8	172.3	**393.4**
WH-1105	1811.4	1413.0	1259.2	1186.4	1096.2	**1353.3**	1104.9	881.0	687.5	612.5	485.3	**754.2**	624.5	507.6	416.8	332.1	200.5	**416.3**
Mean (D)	**1549.0**	**1330.5**	**1230.6**	**1164.0**	**958.8**	**1246.6**	**1073.0**	**835.3**	**670.1**	**596.0**	**414.9**	**717.9**	**631.9**	**505.7**	**414.5**	**322.3**	**200.8**	**415.0**
CD at 5%	**D= 35.24, G= 44.58, DxG= 99.69**						**D= 21.04, G= 26.62, DxG= 59.53**						**D= 10.79, G= 13.65, DxG= 30.53**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 47: Response of wheat genotypes to drought and high temperature for number of grain per spike under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	44.4	42.9	42.1	41.2	39.8	**42.1**	43.7	40.5	40.1	38.4	36.7	**39.9**	41.6	39.2	38.5	37.3	35.9	**38.5**
C-306	53.7	50.5	49.6	47.5	46.6	**49.6**	49.6	48.7	47.5	45.7	44.2	**47.1**	44.3	41.0	40.0	38.3	36.5	**40.0**
DHTW-60	55.6	54.1	52.5	48.9	47.5	**51.7**	58.7	56.3	54.2	51.8	49.0	**54.0**	57.9	55.4	52.9	50.7	48.8	**53.1**
HD-2967	55.7	54.8	52.6	51.3	50.5	**53.0**	57.3	55.6	52.4	50.1	50.0	**53.1**	56.0	54.7	51.9	49.0	47.6	**51.8**
HTW-11	51.4	49.8	46.5	46.3	43.9	**47.6**	55.3	52.8	49.8	49.2	47.3	**50.9**	54.3	53.5	48.5	46.9	45.4	**49.7**
KUNDAN	54.5	52.4	50.6	47.8	46.9	**50.4**	53.9	50.0	48.1	47.0	45.8	**49.0**	46.7	47.0	44.9	43.6	43.9	**45.2**
WH-730	48.2	48.7	43.6	46.2	40.7	**45.5**	49.5	45.0	43.5	42.6	41.3	**44.4**	45.0	43.9	40.3	38.7	38.0	**41.2**
WH-1105	61.1	59.7	55.3	55.0	53.8	**57.0**	56.7	54.3	50.4	49.4	47.5	**51.7**	48.3	48.7	47.6	48.0	46.2	**47.8**
Mean (D)	**53.1**	**51.6**	**49.1**	**48.0**	**46.2**	**49.6**	**53.1**	**50.4**	**48.3**	**46.8**	**45.2**	**48.7**	**49.3**	**47.9**	**45.6**	**44.1**	**42.8**	**45.9**
CD at 5%	**D= 0.77, G= 0.93, DxG= 1.90**						**D= 0.87, G= 0.97, DxG= 1.87**						**D= 0.62, G= 0.75, DxG= 1.77**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 48: Response of wheat genotypes to drought and high temperature for grain weight per spike under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+D65	DR			D40	D65	D40+D65	DR			D40	D65	D40+D65	DR	
AKAW 3717	2.65	2.36	2.00	1.78	1.60	**2.08**	2.20	1.86	1.62	1.36	1.12	**1.63**	2.07	1.70	1.23	0.94	0.58	**1.30**
C-306	2.87	2.54	2.16	1.82	1.66	**2.21**	2.29	1.89	1.72	1.48	1.40	**1.76**	2.10	1.72	1.27	1.00	0.71	**1.36**
DHTW-60	3.04	2.70	2.20	1.88	1.75	**2.31**	2.61	2.04	1.84	1.60	1.58	**1.93**	2.59	2.07	1.64	1.43	1.33	**1.81**
HD-2967	3.16	2.81	2.23	1.91	1.78	**2.38**	2.54	2.01	1.83	1.58	1.54	**1.90**	2.50	1.99	1.59	1.32	1.19	**1.72**
HTW-11	2.80	2.49	2.09	1.81	1.65	**2.17**	2.40	1.96	1.77	1.56	1.46	**1.83**	2.40	1.92	1.51	1.24	1.12	**1.64**
KUNDAN	2.94	2.67	2.18	1.86	1.72	**2.27**	2.33	1.91	1.75	1.50	1.42	**1.78**	2.24	1.80	1.35	1.11	1.04	**1.51**
WH-730	2.73	2.42	2.03	1.81	1.62	**2.12**	2.24	1.87	1.68	1.40	1.29	**1.70**	2.20	1.73	1.32	1.05	0.99	**1.46**
WH-1105	3.52	2.98	2.25	1.97	1.79	**2.50**	2.41	1.97	1.80	1.58	1.52	**1.86**	2.28	1.87	1.47	1.19	1.05	**1.57**
Mean (D)	**2.96**	**2.62**	**2.14**	**1.86**	**1.70**	**2.26**	**2.38**	**1.94**	**1.75**	**1.51**	**1.42**	**1.80**	**2.30**	**1.85**	**1.42**	**1.16**	**1.00**	**1.55**
CD at 5%	**D= 0.032, G= 0.040, DxG= 0.090**						**D= 0.029, G= 0.041, DxG= 0.081**						**D= 0.021, G= 0.032, DxG= 0.058**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Average number of grains per spike for genotypes ranged from 42.1 and 57.0 (timely sown), 39.9 and 54.0 (late sown) and 38.5 to 53.1 (very late sown). Genotype WH-1105 (57.0), HD-2967 (53.0) followed by DHTW-60 (51.7) had earliest day to heading under timely sown condition. Combined effects of heat and drought stress showed that DHTW-60 (54.0) and HD-2967 (53.1) followed by WH-1105 (51.7) had earliest day to heading under late sown condition and genotypes DHTW-60 (53.1) and HD-2967 (51.8) followed by HTW-11 (49.7) under very late sown condition. Genotype AKAW-3717 showed maximum reduction in average number of grains per spike among all genotypes under all drought and delayed sowing conditions.

4.5.1 Grain weight per spike (g)

Grain weight per spike showed significant reduction in all genotypes along with time of drought application and delayed sowing condition (Table 48). Drought application reduced the grain weight per spike in timely, late and very late sown conditions and maximum reduction in grain weight per spike were found in drought condition (2.96 g) under very late sown condition and minimum reduction in grain weight per spike were observed in compete drought stress (1.00 g) under timely sown condition.

Average grain weight per spike for different drought stress condition ranged from 1.70 to 2.96 g (timely sown), 1.42 to 2.38 g (late sown) and 1.00 to 2.30 g (very late sown). The drought situation of D65, D40+D65, and complete drought resulted significant reduction in grain weight per spike (2.14, 1.86 and 1.70 g) under timely sown, (1.75, 1.57 and 1.42 g) under late sown and (1.42, 1.16 and 1.00 g) under very late sown condition respectively. Significant difference was found for grain weight per spike in all genotypes and different drought stress condition with significant interaction effect for drought and genotypes.

Average grain weight per spike for genotypes ranged from 2.08 to 2.50 g (timely sown), 1.63 to 1.93 g (late sown) and 1.30 to 1.81 g (very late sown). Genotype WH-1105 (2.50 g) followed by HD-2967 (2.38 g) and DHTW-60 (2.31 g) had maximum grain weight per spike under timely sown condition whereas, combined effects of heat and drought stress showed that DHTW-60 (1.93 g) and HD-2967 (1.90 g) followed by WH-1105 (1.86 g) had maximum grain weight per spike under late sown condition and genotypes DHTW-60 (1.81 g) and HD-2967 (1.72 g) followed by HTW-11 (1.64 g) under very late sown condition. Genotype AKAW-3717 showed maximum reduction in average grain weight per spike among all genotypes under all drought and delayed sowing conditions.

4.5.2 Grain yield per square meter (g)

Data presented in Table 49 showed combined and individual effects of drought and high temperature (delayed sowing) for grain yield per square meter. Application of drought showed

reduction in grain yield per square meter under timely, late and very late sown conditions and maximum reduction in grain yield per square meter were found in complete drought situation (169.4 g) under very late sown condition and minimum reduction in grain yield per square meter were observed in compete drought stress (207.6 g) under timely sown condition.

Average grain yield per square meter for different drought stress condition ranged from 207.6 to 525.7 g (timely sown), 208.1 to 402.7 g (late sown) and 169.4 to 341.7 g (very late sown). The drought situation of D40+D65, and complete drought resulted significant reduction in grain yield per square meter (355.6 and 207.6 g) under timely sown, (327.1 and 208.1 g) under late sown and (219.5 and 169.4 g) under very late sown condition respectively. Significant difference was found for grain yield per square meter in all genotypes and different drought stress condition with significant interaction effect for drought and genotypes.

Average grain yield per square meter for genotypes ranged from 307.6 to 576.3 g (timely sown), 223.8 to 456.0 g (late sown) and 192.2 to 350.4 g (very late sown). Genotype WH-1105 (576.3 g) followed by HD-2967 (490.3 g) and DHTW-60 (400.7 g) had maximum grain yield per square meter under timely sown condition whereas, combined effects of heat and drought stress showed that DHTW-60 (456.0 g) and HD-2967 (427.5 g) followed by WH-1105 (367.4 g) had maximum grain yield per square meter under late sown condition and genotypes DHTW-60 (350.4 g) and HD-2967 (427.5 g) followed by HTW-11 (367.4 g) under very late sown condition. Genotype AKAW-3717 showed maximum reduction in average grain yield per square meter among all genotypes under all drought and delayed sowing conditions.

4.5.3 1000 grain weight (g)

The significant reduction in 1000 grain weight (g) in all genotypes along with time of drought application and delayed sowing condition are shown in Table 50. Drought application reduced the 1000 grain weight in timely, late and very late sown conditions under different drought situation and maximum 1000 grain weight were found in control (irrigated) condition (56.1 g) under timely sown condition and minimum 1000 grain weight was observed in compete drought stress (23.3 g) under very late sown condition.

Average 1000 grain weight for different drought stress condition varied from 36.6 to 56.1 g (timely sown), 31.2 to 45.0 g (late sown) and 23.3 to 46.9 g (very late sown). The drought situation of D40+D65, and complete drought resulted significant reduction in 1000 grain weight under timely sown (38.9 and 36.6 g), in late sown (32.1 to 31.2 g) and in very late sown (26.2 and 23.3 g) respectively. Significant difference was found in all genotypes and different drought stress condition and interaction effects between genotypes and different drought condition under timely, late and very late sown condition.

Table 49: Response of wheat genotypes to drought and high temperature for grain yield per square meter (g) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+65	DR			D40	D65	D40+65	DR			D40	D65	D40+65	DR	
AKAW 3717	471.2	394.5	331.9	249.3	90.9	**307.6**	309.2	269.2	253.3	219.2	67.9	**223.8**	278.6	224.8	187.1	150.5	119.8	**192.2**
C-306	495.9	406.3	362.1	307.1	152.4	**344.8**	368.7	329.9	315.0	283.3	150.4	**289.5**	281.3	222.8	185.7	154.0	120.6	**192.9**
DHTW-60	513.8	485.7	428.3	359.6	215.9	**400.7**	504.4	488.3	473.9	444.6	368.6	**456.0**	435.1	391.3	355.8	324.1	245.5	**350.4**
HD-2967	580.2	545.3	518.7	471.6	334.2	**490.0**	482.6	459.8	447.6	424.5	322.8	**427.5**	390.2	352.4	322.6	283.7	211.6	**312.1**
HTW-11	490.2	443.8	379.2	304.2	148.6	**353.2**	393.5	349.1	334.2	312.5	200.4	**317.9**	368.7	326.6	290.9	257.1	165.2	**281.7**
KUNDAN	503.3	448.4	386.1	318.5	196.4	**370.5**	377.0	350.2	327.3	293.7	159.1	**301.5**	294.9	258.9	214.1	176.8	128.9	**214.7**
WH-730	478.6	411.2	335.3	273.7	119.9	**323.7**	363.9	321.0	304.0	274.3	140.9	**280.8**	288.9	240.6	205.3	160.0	149.4	**208.8**
WH-1105	672.4	642.9	602.7	560.7	402.7	**576.3**	422.6	403.5	391.6	364.8	254.7	**367.4**	396.2	324.8	306.3	250.1	213.9	**298.3**
Mean (D)	**525.7**	**472.3**	**418.0**	**355.6**	**207.6**	**395.8**	**402.7**	**371.4**	**355.9**	**327.1**	**208.1**	**333.0**	**341.7**	**292.8**	**258.5**	**219.5**	**169.4**	**256.4**
CD at 5%	**D= 11.36, G= 14.32, DxG= 32.12**						**D= 5.52, G= 9.51, DxG= 21.27**						**D= 4.16, G= 5.83, DxG= 13.03**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 50: Response of wheat genotypes to drought and high temperature for 1000 grain weight (g) under timely, late and very late sown conditions

Genotypes	Timely sown						Late sown						Very late sown					
	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)	Control	Time of drought application				Mean (G)
		D40	D65	D40+65	DR			D40	D65	D40+65	DR			D40	D65	D40+65	DR	
AKAW 3717	50.9	47.0	40.3	34.7	32.6	**41.1**	41.6	35.8	33.7	29.7	28.2	**33.8**	43.2	35.3	28.3	22.9	16.1	**29.2**
C-306	54.7	49.8	42.8	39.1	36.2	**44.5**	43.2	36.5	35.1	31.1	30.6	**35.3**	44.1	35.9	30.1	24.8	16.2	**30.2**
DHTW-60	58.2	51.2	46.5	39.2	37.9	**46.6**	50.3	45.8	40.3	35.4	34.0	**41.2**	49.9	43.3	33.4	29.2	27.9	**36.8**
HD-2967	59.7	54.4	47.4	39.3	40.1	**48.2**	47.0	42.1	39.5	34.7	32.1	**39.1**	49.8	42.1	33.0	28.7	27.5	**36.2**
HTW-11	54.1	49.8	42.0	38.5	34.8	**43.8**	45.5	37.4	35.7	31.6	31.4	**36.3**	49.6	40.9	31.9	27.4	27.2	**35.4**
KUNDAN	55.9	51.0	43.4	39.2	36.3	**45.1**	43.3	36.6	35.5	31.2	31.3	**35.6**	46.3	37.8	30.9	25.4	24.1	**32.9**
WH-730	51.7	48.0	41.0	38.0	34.5	**42.6**	42.6	36.2	34.9	30.5	30.5	**34.9**	45.0	36.6	30.6	25.2	22.8	**32.0**
WH-1105	63.2	54.9	47.9	43.3	40.5	**50.0**	46.2	39.2	36.9	32.7	31.6	**37.3**	47.3	38.5	31.6	26.0	24.5	**33.6**
Mean (D)	**56.1**	**50.8**	**43.9**	**38.9**	**36.6**	**45.2**	**45.0**	**38.7**	**36.5**	**32.1**	**31.2**	**36.7**	**46.9**	**38.8**	**31.2**	**26.2**	**23.3**	**33.3**
CD at 5%	**D= 1.70 G= 0.88, DxG= 1.96**						**D= 0.54, G= 0.69 DxG= 1.54**						**D= 0.52, G= 0.66, DxG= 1.48**					

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Average 1000 grain weight for genotypes ranged from 41.1 to 50.2 g (timely sown), 33.8 to 41.2 g (late sown) and 29.2 to 36.8 g (very late sown). Genotype WH-1105 (50.0 g) followed by HD-2967 (48.2 g) had maximum 1000 seed weight under timely sown condition whereas, genotypes DHTW-60 (41.2 g) and HD-2967 (39.1 g) followed by WH-1105 (37.3 g) had maximum 1000 grain yield under late sown condition and genotypes DHTW-60 (36.8 g) and HD-2967 (36.2 g) followed by HTW-11 (35.4) under very late sown condition. Genotype AKAW-3717 showed maximum reduction in average 1000 grain weight among all genotypes under combined effects of heat and drought stress.

4.5.4 Susceptibility index for grain yield (SSI)

Increases in susceptibility index for grain yield are presented in Table 51. Drought application at different growth stages increased susceptibility index for grain yield in timely, late and very late sown conditions and maximum susceptibility index for grain yield was observer for genotype AKAW-3717 at complete drought condition under late sown (1.63), followed by very late sown drought condition in same genotype; AKAW-3717 (1.33) whereas, minimum susceptibility index for grain yield was observed in genotype WH-1105 (0.48) under timely sown when drought was given at 40 days after sowing condition as compare to irrigated condition. Significant difference was found for susceptibility index for grain yield in all genotypes and different drought stress condition. Significant interaction effects were found between genotypes and different drought condition with delayed sowing condition.

Average susceptibility index for grain yield for genotypes ranged from 0.48 to 1.35 (timely sown), 0.53 to 1.63 (late sown) and 0.75 to 1.33 (very late sown). Under timely sown condition genotype WH-1105 (0.48) and genotype HD-2967 (0.55) showed tolerant behavior and under late sown condition genotype DHTW-60 (0.53) showed tolerant behavior and genotype HD-2967 (0.63) followed by WH-1105 (0.68) found moderately tolerant whereas, under very late sown. Genotype DHTW-60 (0.75) and HD-2967 (0.78) moderately tolerant at different drought condition. Genotype AKAW-3717 followed by KUNDAN showed maximum susceptibility index for grain yield and found as most susceptible genotype among all genotypes under all drought and delayed sowing conditions.

Mean sum of square for yield parameters (biomass per square meter, yield per square meter and 1000 grain weight) in Table 52 indicated significant difference in genotypes with drought treatments (D) *i.e* D40, D65, D40+D65 and complete drought & due to sowing time (S) *i.e* timely, late and very late. Interaction effects between genotypes, drought and sowing time has indicated considerable variation for yield parameters.

Table 51: Response of wheat genotypes to drought and high temperature for susceptibility index for grain yield (SSI) under timely, late and very late sown conditions

Genotype	Timely sown					Timely sown					Timely sown				
	Time of drought application				Mean (G)	Time of drought application				Mean (G)	Time of drought application				Mean (G)
	D40	D65	D40+65	DR		D40	D65	D40+65	DR		D40	D65	D40+65	DR	
AKAW 3717	1.60	1.40	1.30	1.10	**1.35**	1.70	1.60	1.60	1.60	**1.63**	1.50	1.40	1.30	1.10	**1.33**
C-306	1.00	1.10	1.10	0.80	**1.00**	1.40	1.30	1.20	1.20	**1.28**	1.30	1.30	1.30	1.10	**1.25**
DHTW-60	0.60	0.80	0.90	0.80	**0.78**	0.40	0.50	0.60	0.60	**0.53**	0.70	0.70	0.70	0.90	**0.75**
HD-2967	0.50	0.50	0.60	0.60	**0.55**	0.60	0.60	0.60	0.70	**0.63**	0.70	0.70	0.80	0.90	**0.78**
HTW-11	1.10	1.10	1.20	0.90	**1.08**	0.90	1.10	1.10	1.00	**1.03**	0.80	0.90	0.80	0.90	**0.85**
KUNDAN	1.40	1.30	1.20	1.00	**1.23**	1.50	1.40	1.30	1.30	**1.38**	1.30	1.20	1.20	1.10	**1.20**
WH-730	0.90	1.00	1.00	0.80	**0.93**	1.40	1.30	1.20	1.20	**1.28**	1.20	1.10	1.10	1.10	**1.13**
WH-1105	0.40	0.50	0.50	0.50	**0.48**	0.60	0.60	0.70	0.80	**0.68**	0.90	0.90	1.00	1.00	**0.95**
Mean (D)	0.94	0.96	0.98	0.81	**0.92**	1.06	1.05	1.04	1.05	**1.05**	1.05	1.03	1.03	1.01	**1.03**
CD at 5%	**D= 0.014, G= 0.020, DxG= 0.040**					**D= 0.017, G= 0.024, DxG= 0.048**					**D= 0.021, G= 0.029, DxG= 0.058**				

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **G-**Genotypes and **D-** Drought

Table 52: Mean sum of square of wheat genotypes for yield parameters (g) in response to drought and high temperature under timely, late and very late sown condition

Source of Variation	df	Biomass per square meter	Yield per square meter	1000 grain weight
Replication	2	50601.642**	48690.050**	60.916**
Genotype (G)	7	3373699.053**	978705.423**	627.635**
Drought Treatment (D)	4	5311699.253**	3763527.001**	5180.152**
GxD	28	311496.630**	115109.931**	118.531**
Sowing Time (S)	2	628133.178**	448805.668**	520.172**
GxS	14	33124.650**	7862.076**	9.130**
DxS	8	23399.322**	13767.091**	14.165**
GxDxS	56	28673.291**	6047.508**	2.866**
Error	238	734.416	378.091	0.730

**** Significant at 1% of significance**

5.0 Soil moisture content (w/w, %)

Table 53 showed data for soil moisture content at different stages (sowing, anthesis, 15 days after anthesis and physiological maturity) under different drought treatment (D40, D65, D40+D65 and complete drought) under different delayed sown environment (timely, late and very late).

Decrease in soil moisture content at different observation stage. Under drought condition of D40+D65 and complete drought showed maximum average reduction in soil moisture content at anthesis (12.29, 11.74 and 11.24 %), at 15 days after anthesis (10.81, 9.98 and 9.75 %), and physiological maturity (7.62, 8.14 and 8.77 %) in timely, late and very late sown condition respectively was observed. Average moisture content for drought condition varied between 9.30 to 13.99 % where, 13.99 % (control), 12.41 % (D40), 11.62 % (D65), 10.13% (D40+D65) and 9.30 % for complete drought condition was found. At physiological maturity minimum soil moisture content at different drought condition very late sown environments was observed.

Table 53: Soil moisture content (w/w, %) in drought and irrigated plot at different growth stages of wheat

Sowing	Observation stage	Control	Drought environment				Mean (S)
			D40	D65	D40+65	Drought	
Timely	Sowing	16.58	16.51	16.36	16.16	16.05	**16.33**
	Anthesis	15.96	14.32	11.48	10.53	9.15	**12.29**
	15 Days after anthesis	14.19	13.35	10.67	8.64	7.18	**10.81**
	Physiological Maturity	8.96	8.62	7.68	7.01	5.85	**7.62**
Late	Sowing	16.57	15.80	15.90	15.45	15.27	**15.80**
	Anthesis	15.84	12.88	12.56	9.42	8.00	**11.74**
	15 Days after anthesis	14.07	10.62	9.64	8.12	7.47	**9.98**
	Physiological Maturity	9.89	8.87	8.36	7.21	6.35	**8.14**
Vary late	Sowing	15.87	15.60	15.37	15.09	15.02	**15.39**
	Anthesis	15.64	12.35	12.17	8.51	7.52	**11.24**
	15 Days after anthesis	13.42	10.18	10.14	8.01	7.01	**9.75**
	Physiological Maturity	10.88	9.81	9.10	7.39	6.67	**8.77**
Mean (D)		**13.99**	**12.41**	**11.62**	**10.13**	**9.30**	

D40- Drought at 40 days after sowing (DAS), **D65-** Drought at 65 DAS, **D40+D65-** Drought both at 40 and 65 DAS, **DR-** Complete drought, **S**- Observation stage and **D-** Drought

Triticum aestivum L. (bread wheat) providing nearly 55 % of the carbohydrates to one third population of world and one of major staple food of north India (Gill *et al.* 2004). Environmental stress, like terminal drought and high temperature and combination of these stresses, cause drastic reduction in wheat grain yield and quality loss which significantly exaggerate the cultivation demand more production (Semenov & Shewry, 2011). Variation of 1 to 2 °C optimal temperature leads to 50 % of yield reduction by disturbing the biological, physiological and biochemical metabolism (Ashraf, 2010). Drought adversely affect near about 50 % of cultivation area word widely and cause yield loss by damaging photosynthetic apparatus (Budak *et al.* 2013). Drought in combination of high temperature is a major limiting factor for growth and productivity as compared to stress applied individually (Pradhan *et al.* 2012).

Drought occurrence just before anthesis and during grain filling declined the number and weight of wheat grains, respectively (Prasad *et al.* 2011). Terminal drought and high-temperature during the wheat reproductive stage reduce carbon assimilation and nitrogen uptake (Altenbach, 2012), resulting in significant quality and quantity reductions (Chaves and Davies, 2010). Drought and high temperature reduces photosynthesis activity through chlorophyll degradation and disruptions of the structure and function of chloroplasts in wheat leaves (Wang *et al.* 2015; Brestic *et al.* 2016). Continuously rising in environmental temperature as well as in combination of drought occur more frequently and will be expected to disturb crop production more harshly (Trnka *et al.* 2014; Ram *et al.* 2017).

The results obtained in the present investigation have been discussed here within the recent literature on the subject with following heads:

5.1 Crop phenological parameters

Crops phenology is the first traits influenced by the environmental stresses such as drought and high temperature (Chu *et al.* 2016). The phenological phase of wheat is having depends on the date of sowing (Dodig *et al.* 2014), temperature (Munjal & Dhanda, 2016); (Dhanda & Munjal, 2017) and (and water availability (Venkateswarlu & Shanker, 2012) throughout the crop session. In present study it was found that drought and delayed sowing shortened the life span of wheat genotype. Reduction in days to heading (Table 1), days to anthesis (Table 2) and days to physiological maturity (Table 3) was found with different drought application with delayed sowing. Maximum reduction in phenology was found under combination of drought with high temperature. Genotype WH-1105 and HD-2967 (timely sown) and DHTW-60 and HD-2967 (late and very late sown) was found in earliest days to heading and anthesis whereas, late in maturity among all genotype observed under drought and

delayed sowing environments. Result of the investigation under study is in line with the result of Hossain *et al.* (2013) they observed that drought and high temperature reduced the growth period for phenological development stages *i.e.* days to heading, days to anthesis, days to grain filling and days to physiological maturity in eight wheat genotype. Ihsan *et al.* (2016) found that delay in planting and reduction in field capacity significantly reduced the days to heading, days to flowering and days to physiological crop maturity as compared to normal irrigation. Shezad *et al.* (2002) reported that yield components directly depend on the days to anthesis and physiological maturity. Late maturing with long grain filling period genotypes showed stress tolerance mechanism and founded high yielding.

5.2 Physiological parameters

Drought in combination with high temperature stress induced significant reduction in osmotic potential (-MPa), leaf water potential (-MPa), relative water content (%), chlorophyll content (SPAD), chlorophyll fluorescence (Fv/Fm) and stem reserve mobilization (%) in the wheat at anthesis and 15 days after anthesis.

5.2.1 Osmotic potential

The osmotic potential (Ψs) represents the effects of the concentration of solutes within water (Taiz and Zeiger, 2010). High temperatures and drought increase the demand for water and reduce the crop water-use efficiency (Ray *et al.* 2002) and extreme amounts of precipitation in the soil can also be responsible for decreases in the water relation in tissue and ultimately yield reduction (Zampieri *et al.* 2017). Drought caused decrease in water content in the plant reducing the water potential and osmotic potential and also decreased the relative water content (Keyvan, 2010). In present study decrease in osmotic potential at anthesis and 15 days after anthesis under the different drought situation was found (Table 4, 5 & 6). Genotype grown under delayed sowing condition (late and very late) showed maximum reduction in osmotic potential as compared to individual stress applied. Reduction in osmotic potential observed among all genotypes but genotype WH-1105, DHTW-60 and HD-2967 showed maintained osmotic potential under timely (Table 4), late (Table 5) and very late sown (Table 6) conditions and indicate significant difference in genotype with drought treatment and sowing environment (Table 7, and Fig. 3 & 4). Our result is similar with the result of Machado and Paulsen (2001) they found high temperature interact with drought and affect water relations by altering osmotic adjustment in wheat and sorghum. Results of present investigation also corroborate the previous study of Datta *et al.* 2011; Ghobadi *et al.* 2011 who observed that exposure of plants to drought and high temperature stress substantially decreased the leaf osmotic potential. Late planted wheat decreased water availability that caused a greater reduction in osmotic potential and turgor potential (Turner, 2017). Reena (2013) also observed reduction in osmotic potential under drought stress conditions, susceptible genotypes (WH 711 and HD 2687) showed

maximum reduction as compared to tolerant genotypes (WH 1021 and WH 1080). Combined effects of drought and high temperature showed more reduction in osmotic potential compared to single stress alone in eight wheat genotypes under drought and two late sown (late and very late) conditions (Ram *et al.* 2017).

5.2.2 Water potential

Drought and high temperature leads to change the physical and chemical properties of soil by increasing strength (Martino & Shaykewich, 1994) and reducing the water uptake ability by creation of air space between soil and root (Nye, 1992). Water and temperature stress under changing environmental conditions significantly reduced the leaf water potential in wheat variety Talagang and PW5 whereas Islamabad and PW2 maintain water status under stress (Ahmed *et al.* 2016). In present investigation reduction in water potential under the different drought situation both at anthesis and 15 days after anthesis was found. Genotype grown under late planting (late and very late condition) with drought condition showed maximum reduction in water potential compared to individual drought and high temperature. Water potential reduced among all genotypes but genotype WH-1105, DHTW-60 and HD-2967 maintained water potential indicated by more negative value under timely (Table 8), late (Table 9) and very late sown (Table 10) condition and indicate significant difference in genotype with drought treatment and sowing environment (Table 11, and Fig. 5 & 6). Finding of present study is in lined with Khan *et al.* (2014); Munjal & Dhanda, (2016); Ram *et al.* (2017) they find that the combined effect of drought and heat significantly decreased the leaf water potential. Abebe *et al.* (2003) in wheat, Behbahanizadeh *et al.* (2014) in barley genotypes also find reduction in water potential compared to irrigated condition and cultivars had a significant difference together in water relation traits. Chunmei *et al.* (2011) study two wheat line of transgenic and wild type and found reduction in leaf water potential both in transgenic and wild type. After drought stress for three days or more, the leaf water potential of transgenic lines L2 and L4 were much more negative than in wild type plants and the differences were statistically significant.

5.2.3 Relative water content

Relative water content (RWC) indicated the relative amount of water present in the tissues, and is a measure of turgor in leaf tissue (Bars & Weatherley, 1962). The RWC was a relevant physiological screening tool for high temperature and drought tolerance in cereals crops, as well as a good indicator of plant water-status (Teulat *et al.* 2003; Pour-Aboughadareh *et al.* 2017). Farooq *et al.* (2009) observed relative water content of wheat leaves was high during leaf development and decreased as the dry matter accumulated. Water stressed in field growing wheat and rice plants had lower RWC than irrigated condition. Sharma *et al.* (2016), find decrease in relative water content on the onset of drought stress in advance barley line. In present study relative water content was significantly decreased under different drought

condition in timely (Table 12), late (Table 13) and very late sown (Table 14) environments. Reduction was more in complete drought and drought created at 40 and 65 days after sowing (D40+D65) at 15 days after anthesis compare to anthesis and irrigate condition in delayed sown condition (late and very late). Genotypes WH-1105, DHTW-60 and HD-2967 maintained water status in term of relative water content in all drought and delayed sowing condition. Combined effects of drought and high temperature indicate significant difference in genotype, drought treatment and sowing time (Table 15). Variation in relative water content was found in all drought situation at anthesis (Fig. 7) and 15 days after anthesis (Fig. 8) with late planting dates. Our result is in accordance with observation of Almeselmani *et al.* (2012); Saxena *et al.* (2014) and Ramani *et al.* (2017) they found decrease in RWC in response to drought and high temperature at different growth stage of wheat.

5.2.4 Chlorophyll fluorescence

Chlorophyll fluorescence reflects the ability of a plant to tolerate environmental stresses and the extent to which stresses can have damaging effect on the photosynthetic apparatus (Maxwell & Johnson, 2000) and a fast reliable tool for analyzed the stress induced changes in photosystem two, which is an important role in the response of leaf photosynthesis to environmental stresses (Naumann *et al.* 2008). Chlorophyll fluorescence extinction measurement are the most reliable test enabling the discrimination of wheat varieties according to their drought tolerance (Sayer *et al.* 2008). The results of present investigation indicated that (Table 16, 17, 18) chlorophyll fluorescence show a declining trend from anthesis to 15 days after anthesis. Maximum reduction was observed under complete drought and drought at 40 and 65 days after sowing (D40+D65) followed by drought at 65 days after sowing (D65) at different delayed sowing condition. Genotypes WH-1105, DHTW-60 & HD-2967 was found to have maximum in chlorophyll fluorescence (Fv/Fm) with respect to different drought application & date of sowing among all genotype. Our result is in line with Almeselmani *et al.* 2012 and Khakwani *et al.* (2012) they found drought and temperature stress significant reduced activity of photosystem chlorophyll fluorescence of ten wheat genotypes. The decrease in chlorophyll fluorescence could be the occurrence of chronic photo-inhibition due to photo-inactivation of PSII centers (Zlatev & Stoyanov, 2005). Wang *et al.* (2010) also reported that combination of drought and heat stress resulted in a more drastic decline of Fv/Fm than each stress alone. Mouradi *et al.* (2016) and Brestic *et al.* 2015 observed the decrease in maximum quantum yield of primary photochemistry (Fv/Fm) under drought conditions.

5.2.5 Chlorophyll content

Chlorophyll is a major photosynthesis site present in chloroplast have directely relationship with photosynthetic rate and flag leaf greenness (Bijanzadeh & Emam, 2010). High chlorophyll content is one of the desirable characteristic that indicates a low degree of photo-inhibition ultimately, reduced the carbohydrate losses during grain growth (Moaveni, 2011;

Swapna & Shylaraj, 2017). Chlorophyll concentration (SPAD) have a significant association with photosynthesis and leaf nitrogen content (Iqbal *et al.* 2013). Wang *et al.* (2010) studied the responses of drought & heat stress on wheat plants and reported that heat and drought decreased the chlorophyll content. The results presented in Table 20, 21 & 22 showed that chlorophyll SPAD units decreased under different drought at anthesis and 15 days after anthesis under delayed sowing condition. Reduction was higher at drought condition of irrigation was withhold at 40 and 65 days after sowing (D40+D65) and complete drought at anthesis and 15 days after anthesis respectively, under all droughts and date of planting (timely, late and very late) condition. Genotype WH 1105, DHTW-60, HD 2967 and HTW-11 maintained high chlorophyll content during grain filling period (15 days after anthesis). Results of this study are in collaboration with pervious study of Almeselmani *et al.* (2011) Chlorophyll content differ significantly among varieties, highest amount of total chlorophyll was recorded after seven days to flowering (Almeselmani *et al.* 2011). Izanloo *et al.* in (2008) who reported that water deficit leads to an increased depletion of chlorophyll and a decreased concentration of chlorophyll. Thalooth *et al.* (2016); Anitha *et al.* (2015); Barutcular *et al.* (2017) reported that withholding irrigation at any growth stage decreased the chlorophyll content. Hui *et al.* (2007) and Naroui *et al.* 2012 also reported 20% reduction in leaf chlorophyll content under drought stress. Pandey *et al.* (2015) and Mishra *et al.* (2017) reported changes in chlorophyll content from anthesis to 15 days after anthesis under late sown condition with drought stress. Almeselmani *et al.* (2012) and Ram *et al.* (2017a) observed significant reduction in chlorophyll content in wheat genotypes with age under late & very late sown condition.

5.2.6 Stem reserve mobilization

Stored stem reserves serve as a source of carbon for grain filling in wheat, particularly during stress conditions (Wardlaw, 1974) and stem is the alternative source of carbon for grain filling by re-translocating of reserved to maintain reproductive growth under stress conditions (Blum *et al.* 1994; Wang *et al.* 2012). Stem reserves mobilization (SRM) for grain filling assumes great importance because current photosynthetic source *i.e.* leaf is adversely influenced under high temperature (Blum *et al.* 1994). Shukla *et al.* (1997) considered stem reserve mobilization as an associated desirable trait in providing tolerance to the drought & heat stress because greater stem reserve mobilization took place in tolerant genotype to support grain filling during critical stages of dry matter accumulation in the grain. The results of present study shown in table 24 & 25 respectively on stem reserve mobilization in peduncle & penultimate internode. Combined effect of stress showed faster remobilization of stem reserve both in peduncle and penultimate internode whereas, peduncle showed faster and higher remobilization in all drought condition and delayed sowing. SRM display an increasing trend among all genotypes under different drought treatments as well as different sowing conditions. Genotype DHTW-60, WH-1105 & HD-2967 showed higher SRM at different time of drought

application and different sowing condition in peduncle and penultimate internode. The results of present investigation is supported by earlier finding of Gupta *et al.* (2011). Sharifi *et al.* (2017) found similar result in wheat genotypes under water-deficit treatments with 50 to 80 % higher mobilization than the in well-watered treatments, which indicates that water deficits promoted remobilization. Ehdaie *et al.* (2008) reported that drought result in increasing mobilization efficiency, expressed as percentage of maximum dry matter mobilized, in the peduncle, penultimate and the lower internodes by 65, 11 and 5 %, respectively in wheat. Under heat stress genotypic variation exists for the contribution of stem reserves for grain filling (Yang *et al.* 2002). Gupta *et al.* (2011) found higher mobilization of dry matter and mobilization efficiency in the internodes of wheat genotypes C-306 and PBW-343, both under control and stress drought stress conditions, which resulted in enhanced translocation of stem reserves to the grains. The long grain filling duration in tolerant cultivar supported enhanced mobilization of stem reserves, thus limiting decrease in grain yield of tolerant cultivar under drought stress conditions as compared to the sensitive cultivar (Joudi *et al.* 2012; Zhang *et al.* 2014).

5.3 Biochemical parameters

Low precipitation caused drought first and secondly induces high temperature that further influenced the success of modern agriculture whole around the world ultimately, affect the plant growth, development and production by altering the carbon metabolic pathway (Hasanuzzaman *et al.* 2013; Yanez *et al.* 2017). Combination of late planting with drought reduce the metabolite level and enzymatic activity at cellular level. Metabolites and enzymatic activity both in peduncle and penultimate internode showed reduction with different drought condition whereas, drought and high temperature combination showed maximum reduction and the reduction was more at 15 days after anthesis as compared to anthesis.

5.3.1 Metabolites

5.3.1.1 Glucose, fructose and sucrose

Glucose, fructose, sucrose, water soluble carbohydrates and cellulose have a vital and potential role in adaptation to drought and high temperature (McKersie & Leshema, 1994; Solomon & Labuschagne, 2005). About 80% of the carbon assimilated during photosynthesis is converted to sucrose (Koch, 2004) and it is major organic exported carbon from the source to sink organs which play a crucial role for survival and productivity of plants (Rizhsky *et al.* 2004). In present study reduction in the glucose, fructose and sucrose under stress condition as compared with normal condition was observed. Concentration of glucose (Fig. 15 and 16), fructose and sucrose was higher in peduncle (Fig. 15, 17 & 18) than penultimate internode (Fig. 16, 18 & 19) at anthesis. Significant reduction in glucose, fructose and sucrose was observed at 15 days after anthesis under different drought condition and delayed sowing. Drought situation D40+D65 and complete drought showed maximum reduction in glucose, fructose and

sucrose concentration with late and very late sown environment both in peduncle and penultimate internode as compare drought condition D40 and D65 individualy. Table 27 (glucose), Table 28 (fructose) and Table 29 (sucrose) represents significant variation in metabolite concentration due to genotypes, drought environment and delayed sowing respectively. Genotypes WH-1105, DHTW-60 and HD-2967 having higher concentration of glucose, fructose and sucrose in peduncle as well as penultimate internode at anthesis and 15 days after anthesis. The results of our study are well in accordance with the result of Tetlow *et al.* (2004); Basu *et al.* (2007); Kempa *et al.* (2008) and Kotting *et al.* (2010) they find similar result under drought and high temperature condition and showed reduction in glucose, fructose, sucrose and fructan level in wheat flag leaf. Willenbrink *et al.* (1998) observed decrease in glucose, fructose and sucrose content in wheat peduncle during grain filling. Saeedipour & Moradi (2011) also confirmed that water stress reduced water soluble carbohydrate, glucose, fructose and fructan concentrations in peduncle of wheat genotype Marvdasht and Zagros.

5.3.1.2 Water soluble carbohydrates

Exposure of high temperature and drought cause considerable morphological damage, which reduced pollen viability (Saini & Aspinall, 1982), starch biosynthesis (Zhao *et al.* 2008) and water soluble carbohydrates (Wang *et al.* 2012). Similar trends of reduction was observed for glucose, fructose & sucrose and also in case of total water soluble carbohydrates under combined and individual effects of drought and high temperature both in peduncle (Fig. 23) and penultimate internodes (Fig. 24) at anthesis and 15 days after anthesis respectively. Reduction in water soluble carbohydrate was significant with date of late planting with different drought condition among all genotypes under study (Table 31) whereas, genotypes WH-1105, DHTW-60 and HD-2967 performed well in adverse condition and found higher concentration of water soluble carbohydrate in peduncle and penultimate internode at anthesis and 15 days after anthesis. Our result is in controversy with Zhang *et al.* (2016) reported that under complete drought conditions were up to 2.5-fold higher for some wheat genotypes. Under non-stress conditions water soluble carbohydrate contribute about 10 to 20% of final grain weight (Gebbing *et al.*1999), but under late planting (high temperature) and drought stress condition this increase upto 50% (van Herwaarden *et al.* 2003; Rebetzke *et al.* 2008; Rattey *et al.* 2009).

5.3.1.3 Stem cell wall polysaccharide (cellulose)

The cellulose content in primary cell walls is in low concentration but it provides mechanical strength to plant (Wolf *et al.* 2012). Cellulose is the major stem cell wall component which is adversely affected by water stress and high temperature (Gall *et al.* 2015; Tenhaken, 2015). Stem cell wall polysaccharide (cellulose) increased in present study at 15 days after anthesis as compared to anthesis but with the combination of drought and high temperature showed reduction in cellulose (stem wall polysaccharide). Peduncle (Fig. 21) and penultimate internode (Fig. 22) showed higher concentration of cellulose at 15 days after anthesis. Mean

sum of square for cellulose (Table. 30) showed significant difference in genotype due to drought and high temperature and interaction between genotype, drought condition and sowing environment. Genotypes WH-1105, DHTW-60 and HD-2967 showed least reduction in stem wall polysaccharide under different drought and late sown condition. Our finding is in line with result of Zhang *et al.* (2010) that find stem cell wall polysaccharide in tested wheat genotype sharply decreased with drought stress and minutely increased with high temperature. Similar kinds of result also observed by Al-Hakimi, (2006); Moore *et al.* (2008); Hu *et al.* (2009); Jiang *et al.* (2012) and Rakszegi *et al.* (2014) in different crops plant.

5.3.2 Carbohydrate metabolizing enzyme

The carbohydrates from photosynthesis after anthesis transport to the grain as sucrose and starch is synthesized in the grain through catalysis by a series of enzymes (Wang *et al.* 2007). Complex phenomena of starch-sucrose biosynthesis is determined by the action of various enzyme activities, in which ADP-glucose pyrophosphorylase (AGPase), sucrose synthase (SuSy), invertase (INV), starch branching enzyme (SBE) and starch debranching enzyme (SDBE) leads to the synthesis of the starch and sucrose granule (Jeon *et al.* 2010; Tetlow, 2011; Ohdan *et al.* 2011). Enzyme activity rapidly declines under water stress and high temperature studied for SuSy (Yang *et al.* 2003), INV (De Coninck, *et al.* 2005), SBE (Xia *et al.* 2011), SDBE (Utsumi *et al.* 2011) and AGPase (Kaur *et al.* 2017).

5.3.2.1 Sucrose synthase

Sucrose synthase is a membrane-associated cytoplasmic enzyme catalyzes the reversible reaction of sucrose hydrolysis into UDP-glucose and fructose, the first step in the conversion of sucrose to starch (Keeling and Myers, 2010). Ge *et al.* (2012) noticed activities of sucrose synthase in two wheat cultivar Ningchun 4 and Chinese spring and found very high activity at anthesis that fall sharply during grain filing. The rise in sucrose synthase activity is positively correlated with the onset of starch and storage protein biosynthesis (Obata-Sasamoto & Susuki, 1979). In present investigation we found reduction in sucrose synthase activity was found under drought and late sown condition in peduncle and penultimate internode (Fig. 25 and 26). Peduncle showed maximum SuSy activity as compared to penultimate internode and activity was more at anthesis then 15 days after anthesis both in peduncle and penultimate internode. Genotype WH-1105, DHTW-60 and HD-2967 was found maximum in SuSy activity under adverse condition. Relationship between genotypes, drought and sowing environment also found significant among treatment and genotypes (Table 32). Sun *et al.* (2006) and Saeedipour, (2011) concluded that drought caused a marked reduction in sucrose synthase at 21 DAA. Various researcher found similar kind of result in wheat (Sharma *et al.* 2005), rice (Weerakoon *et al.* 2008) and cotton (Cottee *et al.* 2010). In wheat stems, activities of both sucrose synthase (Wardlaw & Willenbrink, 1994) and acid invertase (Bancal & Triboï, 1993) have been found to be very high at anthesis and fall sharply during grain filing. Yang *et*

al. (2004) also observed reduction in sucrose synthase under drought with combination of high temperature stress.

5.3.2.2 Invertase

Environmental stress negatively affect the cell wall-bound invertase activity when the plants were subjected to a water shortage and shifting the date of planting (Zinselmeier *et al.* 1995). Invertase activity was highest in wheat genotype Acc 7079 when pooled across drought and high temperature (Suneja *et al.* 2015). In present investigation invertase activity showed reduction under combined stress as compared to timely sown irrigated condition. Reduction pattern was quite similar both in peduncle (Fig. 27) and penultimate internode (Fig. 28) at anthesis and 15 days after anthesis in all genotype tested. Interaction effect between genotypes, late planting and drought environment was significant and drought condition D40+D65 & complete drought showed maximum reduction at 15 days after anthesis (Table 33). Genotype WH-1104 and HD-2967 showed higher invertase activity in both peduncle and penultimate internode. Our result is accordance of Weber *et al.* (2005); Pugh *et al.* (2010); Ruan *et al.* (2010) for high temperature and drought during grain-filling period affects the invertase activity.

5.3.2.3 Starch branching enzyme

Amylopectin is formed by the action of starch branching enzyme and form α-1,6-glucosidic linkages of α-glucan during starch biosynthesis (Emes *et al.* 2003). Drought followed by temperature reduce amylose and amylopectin content and reduced starch branching enzyme in wheat genotype (Regina *et al.* 2015). Starch branching enzyme activity was decreased in present study at anthesis and 15 days after anthesis both in peduncle and penultimate internode. Peduncle (Fig. 29) and penultimate internode (Fig. 30) showed higher activity of SBE at anthesis. Mean sum of square for SBE (Table 34) showed significant difference in genotype due to drought and high temperature and interaction between genotype, drought condition and sowing environment. Genotypes WH-1105, DHTW-60 and HD-2967 showed least in reduction in starch branching enzyme under different drought and late sown condition. The results of present investigation are supported by earlier finding of Gupta *et al.* (2011); Jeon *et al.* (2010); Tetlow & Emes, (2014); Sharifi *et al.* (2017) they found limited activity of SBE under drought and terminal heat stress.

5.3.2.4 Starch debranching enzyme

Starch debranching enzyme (SDBE) is a main enzyme involved in sucrose-starch metabolic mechanism in cereal (wheat and rice) endosperm (James *et al.* 2003; Jeon *et al.* 2010) and hydrolyzed α-1,6-glucosic linkages of polyglucans (Wei *et al.* 2011). Result presented in Fig. 31 and Fig. 32 for starch debranching enzyme showed reduction in enzyme activity with application of drought at different growth stages in peduncle and penultimate internode at anthesis and 15 days after anthesis but with delayed sowing condition (high temperature) was observed increasing trends of starch debranching enzyme at 15 days after anthesis. Combined

effect of drought showed significant variation in starch debranching enzyme at anthesis and 15 days after anthesis both in peduncle and penultimate internode of tested genotypes (Table 35). Genotype HD-2967 and DHTW-60 had maximum SDBE activity among all genotypes under late planting and drought condition. Our finding is in accordance with the result of Shevkani *et al.* (2017) where the starch debranching enzyme activity in genotypes of *triticales* increased rapidly at the anthesis, reaching the maximum at 14 days after anthesis and decreasing slightly after 21 days after anthesis respectively, constant at the last stage of kernel (28 DAA) development. Cheng *et al.* (2005) and Wei *et al.* (2010) observed reduction in starch branching enzyme activity under drought condition in rice.

5.3.2.4 ADP-glucose pyrophosphorylase

ADP-glucose pyrophosphorylase catalyzes ADP-Glucose, the first step in starch biosynthesis (Thitisaksakul *et al.* 2012) and regulated by high temperature and drought stress (Boehlein *et al.* 2008). Zhang *et al.* 2012 observed that decreases in AGPase activity and grain yield in maize and wheat. Batra *et al.* (2017) find that AGPase and grain growth rate are directly correlated and effect the wheat productivity.

In present investigation we found reduction in ADP-glucose pyrophosphorylase activity under drought and late sown condition in peduncle and penultimate internode (Fig. 33 and 34). Peduncle showed maximum AGPase activity as compare to penultimate internode and activity was more at anthesis then 15 days after anthesis both in peduncle and penultimate internode. Genotype WH-1105, DHTW-60 and HD-2967 was found to have maximum in AGPase activity under adverse condition. Relationship between genotypes, drought and sowing environment also found significant among treatment and genotypes (Table 36). Johnson *et al.* (2003); Kang *et al.* (2010); Kaur *et al.* (2017) reported that decrease in AGPase activity in wheat genotype due to combined high temperature and drought stress can be attributed to the corresponding decrease in the starch content and hence grain yield.

5.4 Yield parameters

5.4.1 Yield and yield attributes

Plant height (cm), Peduncle and penultimate internode length (cm), Peduncle and penultimate dry weight (mg), number of spikelet/spike, spike length (cm), number of productive tiller per square meter, biomass (g/m^2), grain yield (g/m^2), 1000 grain weight (g) & SSI were reduced by the combined effects of drought and heat stress. Various researcher Laghari *et al.* (2012); Garg *et al.* (2012); Dhyani *et al.* (2013); Saxena *et al.* (2016); Dwivedi *et al.* (2017) found that high temperature stress during reproductive stage of wheat has destructive effects on test weight, biomass, grain weight, spikelets/spike, spike length, no. of tiller and susceptibility index and grain yield. Drought effects on wheat production, reduced grain weight, grain number and decrease in carbohydrate level. Similar response found by (Gutteri *et al.* 2000, 2001; Asseng *et al.* 2011; Hamid *et al.* 2012; Passioura, 2012; Pradhan *et*

al. 2012; Chen *et al.* 2015). Number of grains per spike, grain weight, grain size and yield get reduced by drought (Chaves, 1991, Shpiler and Blum, 1991, Cornic, 2000; Rashid *et al.* 2003, Flexas *et al.* 2004, Anjum *et al.* 2011, Balota *et al.* 2008).

In present study yield and yield attributes *viz.* plant height (Table 37), peduncle (Table 38) and penultimate internode length (Table 40), peduncle (Table 39) and penultimate dry weight (Table 41), number of spikelet/spike (Table 43), spike length (Table 44), number of productive tiller per square meter (Table 45), biomass per square meter (Table 46), number of grain per spike (Table 47), grain yield per spike (Table 48), yield per square meter (Table 49) and 1000 grain weight (Table 50) showed a wide range of variation with different drought imposed at 40, 65 and 40+65 days after sowing condition and delayed in time of sowing. Late planting with drought stress at different vegetative growth stage reduced yield and related attributes. Genotype DHTW-60, C-306 and AKAW-3717 was found to have maximum in plant height, peduncle and penultimate internode length whereas, DHTW-60, C-306, HTW-11 and HD-2967 had maximum peduncle and penultimate internode dry weight. Genotype DHTW-60, HD-2967, WH-1105 and HTW-11 was found maximum in biomass per square meter, yield per spike, number of grain per spike, 1000-seed weight and yield per square meter under drought situation with delayed sowing. Similar findings have also been reported by various workers (Noorka *et al.* 2009; Farooq *et al.* 2014; Cimini *et al.* 2015; Verspreet, 2015; Brestic *et al.* 2016, Munjal & Dhanda, 2016; Zampieri *et al.* 2017; Mishra *et al.* 2017 and Ram *et al.* 2017). Dwivedi *et al.* (2017) also reported high reduction in tiller number (51.2%), spike length (39.9 %) & grain yield (60.3%). Maich *et al.* (2017) reported elevated temperature caused a reduction in grain yield between 6-21% as compared normal grown varieties. Chatha *et al.* (1999); Aynehband *et al.* (2011) and Wang *et al* (2017) reported that shoots length and dry weight of wheat plant depends on different dates of sowing and water availability.

5.4.2 Grain growth rate and grain filling duration

Grain filling duration and grain growth rate are two important factor for potential grain weight recognition, Grain filling duration seems to be more affected by environmental factors than grain growth rate (Royo *et al.* 2003). Drought and high temperature during grain-filling period showed significantly decreased in grain growth rate by reducing the grain filling duration (Altenbach *et al.* 2003; Laxman *et al.* 2014). Stress during post-anthesis grain growth duration is considered as most significant determinant wheat yield (Mitra & Bhatia 2008). Delayed planting reduced duration of grain filling and dry weight accumulation in wheat genotypes (Ray & Ahmed, 2016; Guo & Schnurbusch, (2015). Our study find reduction in grain growth rate (Fig. 35, 36, 37, 38 and 39) and days to grain filling duration (Table 42) under late sown environment with different drought situation. Maximum grain filling duration and grain growth rate was procured by genotype DHTW-60 and HD-2967 under all stress condition. Sharma *et al.* (2014) and Uddin *et al.* (2015) find higher grain growth rate in four wheat genotype under different delayed sowing.

Karim *et al.* (2000) and Abdul *et al.* (2012) also supported that both higher grain growth rate & longer growth duration in heat tolerant wheat are responsible for its higher grain yield under late sowing conditions.

5.4.3 Susceptibility index for grain yield

Susceptibility index is the measurement of yield stability on the basis of changes in both potential and actual yields in stressed environments (Fischer and Maurer, 1978). Clarke *et al.* (1992) used stress susceptibility index for evaluation of wheat genotype. Guttieri *et al.* (2001) ranked wheat genotype and conclude that genotype had less SSI are stress tolerant. Our investigation showed increased susceptibility index (Table 51) with application of drought at different growth stage under delayed sowing. Most of genotype under drought condition of D40+D65 and complete drought showed susceptible behavior except DHTW-60 and HD-2967. These promising genotype showed tolerant behavior under timely and late sown whereas, moderately tolerant under very late under complete drought and D40+D65 conditions. Results of present work are argued with Dotlacil *et al.* 2010; Dehbalaei *et al.* (2013); Sareen *et al.* (2014); Munjal & Dhanda, (2016) and Dhanda & Munjal, (2017) they find similar result under drought and high temperature condition. Resistance of genotypes are strongly bounded with genotype and environmental interaction (Golabadi *et al.* 2005). SSI can use to evaluate wheat genotypes for breeding under stress conditions (Menshawy *et al.* 2006). Sio-Se *et al.* (2006) find SSI ranged between 0.2 to 0.9 for tolerant genotype.

5.5 Soil moisture

Reduction in soil moisture influences the photosynthesis and ultimately had significant effect on total plant dry weight (Ghosh *et al.* 2013). Low soil moisture increase faster senescence, shorten life cycle and poor grain yield (Ahmed *et al.* 2013; Reynold *et al.* 2016). Water stress impact on vegetative and reproductive growth, yield, membrane integrity, pigment content, osmotic adjustment, relative water concentration and photosynthetic performance (Praba *et al.* 2009; Sharma *et al.* 2016). The data presented in Table 52 indicate soil moisture at different observation stages. Reduction in soil moisture was noticed under different drought condition. Our investigation was accordance to Demirevska *et al.* 2009; Ahmed *et al.* 2013; Blum, (2016); Ramya *et al.* 2017 who showed yield penalty under reduction in soil moisture.

CHAPTER-VI

SUMMARY AND CONCLUSION

The present investigation was aimed to study the carbohydrate metabolism in wheat under drought and high temperature conditions. The experiment was conducted in randomized block design to investigate the effects of drought and heat stress and to identify physiological and biochemical traits related to accumulation and partitioning of carbohydrate under drought & heat respectively. Eight wheat genotypes namely AKAW-3717, DHTW-60, C-306, HD-2967, HTW-11, KUNDAN, WH-730 and WH-1105 were used to study various phenological, physiological, biochemical and yield parameters. Drought created both at 40 and 65 days after sowing was found most critical in declining all the parameters under study followed by drought at 65 days after sowing under the timely, late and very late sowing condition. Salient findings and conclusions of the present investigations are detailed below:

6.1 Phenological parameters

6.1.1 Days to heading, days to anthesis and days to physiological maturity significantly decreased different drought application of different days after sowing (40, 65, 40+65 and complete drought with delayed sowing (late and very late sowing).

6.1.2 Complete drought throughout the crop season under timely sown condition caused earliest day to heading (82.2), days to anthesis (90.1) & days to maturity (123.3); under late sown condition earliest day to heading (76.4), days to anthesis (80.9) & days to maturity (111.5) whereas minimum day to heading (64.2), days to anthesis (68.1) and days to maturity (89.1) was observed under very late sown condition.

6.2 Physiological parameters

6.2.1 Drought in combination with high temperature showed reduction in relative amount of water in tissue that reduced chlorophyll content & chlorophyll fluorescence among all genotype at anthesis and 15 days after anthesis and faster peduncle and penultimate internode remobilization.

6.2.2 Reduction in water relation traits (osmotic potential, water potential and relative water content) under the different drought condition both at anthesis and at 15 days after anthesis was found. Genotypes grown under late planting (late and very late) with drought condition showed maximum reduction in water relation traits compared to individual drought and high temperature.

6.2.3 Maximum reduction in physiological parameters was found under complete drought and drought both at 40 and 65 days after sowing followed by drought at 65 days after sowing. Combined effects of drought and high temperature showed sharp reduction in water relation traits, chlorophyll related traits.

6.2.4 Highest osmotic potential was found in WH-1105 (-1.91 and -2.03 MPa) under timely sowing at anthesis and 15 days after anthesis respectively, whereas genotype DHTW-60 (-2.05 and -2.32 MPa; -2.16 and -2.62 MPa) followed by HD-2967 (-1.96 and -2.18; -2.07 and -2.30 MPa) under late and very late sown at anthesis and 15 days after anthesis respectively.

6.2.5 Maximum water potential (less negative) was observed in genotype WH-1105 (-1.27 and -1.40 MPa) under timely sowing whereas, DHTW-60 (-1.33 and -1.45 MPa; -1.45 and -1.60 MPa) followed by HD-2967 (-1.49 and -1.52; -1.62 and -1.75 MPa) under late and very late sown at anthesis and 15 days after anthesis respectively.

6.2.6 Highest relative water content was detected in WH-1105 (80.5 and 78.1 %) under timely sowing at anthesis and 15 days after anthesis respectively, whereas genotype DHTW-60 (76.3 and 71.0 %; 75.4 and 71.4 %) followed by HD-2967 (75.5 and 70.5; 70.2 and 69.8 %) under late and very late sown at anthesis and 15 days after anthesis respectively.

6.2.7 Maximum water potential (less negative), osmotic potential (more negative) and relative water content was observed in genotype WH-1105 under timely sowing whereas, under late and very late sown at anthesis and 15 days after anthesis it was found in DHTW-60 followed by HD-2967.

6.2.8 Maximum quantum efficiency of photosystem-II in term of chlorophyll fluorescence was maintained by genotypes WH-1105, DHTW-60 and HD-2967 at anthesis and 15 days after anthesis under all drought and high temperature condition.

6.2.9 Chlorophyll content (SPAD) declined under drought and delayed sowing and maximum SPAD value was found in genotype DHTW-60, HD-2967 and WH-1105.

6.2.10 Reserve mobilization from the peduncle and penultimate internode showed positive association with stem dry matter and stem water soluble carbohydrates.

6.2.11 Under delayed sowing with combination of different drought condition, faster remobilization was observed in genotype DHTW-60 and HD-2967.

6.3 Biochemical parameters

6.3.1 Drought in combination with late planting reduced carbohydrate metabolizing enzyme activity and metabolite accumulation in peduncle and penultimate both at anthesis and 15 days after anthesis.

6.3.2 Glucose, fructose and sucrose decline under different drought condition and late planting date at anthesis and 15 days after anthesis. Reduction in glucose, fructose and sucrose content was maximum at 15 days after anthesis under complete drought and D40+D65 days after sowing followed by drought at 65 days after anthesis.

6.3.3 Water soluble carbohydrates found maximum at anthesis in penultimate internode under different drought condition and peduncle at 15 days after anthesis.

6.3.4 Genotypes DHTW-60, WH-1105 and HD-2967 was found to have maximum glucose, fructose, sucrose and water soluble carbohydrate at anthesis and 15 days after anthesis both in peduncle and penultimate internode.

6.3.5 Under delayed sowing condition stem cell wall polysaccharide (cellulose) decreased with different drought condition. Genotypes DHTW-60, WH-1105 and HD-2967 showed maximum cellulose content at anthesis and 15 days after anthesis both in peduncle and penultimate internode.

6.3.6 The activity of carbohydrate metabolizing enzyme sharply decreased under complete drought followed but drought at 40 and 65 days after sowing at 15 days after anthesis under late and very planting condition

6.3.7 Sucrose synthase showed a peak value at anthesis in peduncle and penultimate internode under all drought conditions.

6.3.8 Reduction in invertase, starch branching enzyme and ADP-glucose pyrophosphorylase decreased under drought and late sown as compared to timely irrigated condition both in peduncle and penultimate internode.

6.3.9 Application of drought reduced starch debranching enzyme activity at different growth stage but terminal heat shock showed increase in enzyme activity in wheat stem.

6.3.10 Genotypes DHTW-60, WH-1105 and HD-2967 showed maximum carbohydrate metabolizing enzyme activity at anthesis and 15 days after anthesis both in peduncle and penultimate internode and maintained maximum concentration of glucose, fructose, sucrose and cellulose in peduncle as well as penultimate internode.

6.4 Yield parameters

6.4.1 Individual and combined effects of drought and high temperature at different days after sowing showed reduction in yield and yield attributes and increased with magnitude of drought at 40 days after sowing (D40) < D65 < D40+D65 < complete drought under late and very late sowing.

6.4.2 Yield parameters like plant height, peduncle and penultimate dry weight and length reduced under different drought and late planting conditions in all genotypes.

6.4.3 Delayed sowing with drought application showed reduction in grain growth rate and grain filling duration in all genotypes. Combined effects of drought and high temperature showed decrease in grain filling duration and significant reduction in grain growth rate. Grain growth rate and grain filling duration was found maximum in DHTW-60, WH-1105 and HD-2967 under timely late and very late sown condition.

6.4.4 Number of spikelets per spike, spike length, number of grain per spike and number of productivity tillers per square meter decreased under drought and late planting.

6.4.5 Combined effects of different drought condition and delayed sowing reduced biomass per square meter, grain weight per spike, grain yield per square meter and 1000 grain weight. Genotype WH-1105 and DHTW-60 under timely sown and genotype DHTW-60 and HD-2967 under late and very late sown condition with different drought situation showed maximum biomass per square meter, grain weight per spike, grain yield per square meter and 1000 grain weight

6.4.6 Stress susceptibility indices showed genotype DHTW-60 and HD-2967 as tolerant and AKAW-3717 and KUNDAN as susceptible in nature.

6.5 Soil moisture

6.5.1 Soil moisture content decreased under different drought condition but D40+D65 and complete drought had maximum reduction in soil moisture content.

6.5.2 Reduction in soil moisture content at D40+D65 resulted in reduction of plant water relation parameters, enzymes activity, remobilization of metabolites and ultimately grain yield.

Effects of drought, high temperature and their combination reduced crop phenology (days to heading, anthesis and physiological maturity), physiology (water status, chlorophyll fluorescence and stem reserve mobilization), biochemical (glucose, fructose, sucrose, total soluble carbohydrate, stem cell wall polysaccharide, sucrose synthase, invertase, ADP-glucose pyrophosphorylase, starch branching and debranching enzyme activity) and ultimately yield. Strong positive correlation between stem dry matter and stem water soluble carbohydrate observes at 15 days after anthesis could be an effective method to estimate the amount of stem reserves accumulated and mobilized to grain.

Physiological traits like osmotic potential, water potential, chlorophyll fluorescence and stem reserve mobilization found strongly associated with biochemical traits like sucrose synthase, ADP-glucose pyrophosphorylase, starch branching and debranching enzyme. These traits may provide best selection criteria for selection of wheat genotype for drought and high temperature tolerance. Wheat genotypes DHTW-60, HD-2967 and WH-1105 was found best and promising in overall performance and may be exploited in future breeding programme in order to improve yield in adverse environment.

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APPENDIX

Appendix 1. Mean table for glucose (mg/g dry wt.) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	37.9	29.8	22.1	11.2	9.0	6.8	30.1	21.9	13.8	9.0	6.8	4.5
C-306	46.5	36.6	24.6	13.6	10.9	7.5	34.8	25.9	15.3	10.3	7.9	4.9
DHTW-60	58.0	56.2	47.0	16.7	16.4	13.8	42.3	40.6	31.4	12.4	12.0	9.4
HD-2967	65.7	53.4	43.1	19.0	15.6	12.7	49.9	37.9	27.6	14.6	11.2	8.3
HTW-11	43.8	45.5	40.1	12.9	13.4	11.9	33.1	30.9	25.1	9.9	9.3	7.6
KUNDAN	52.2	41.2	30.7	15.2	12.2	9.2	37.1	29.1	19.0	11.0	8.8	5.9
WH-730	40.9	32.0	27.4	12.1	9.6	8.3	31.9	23.1	16.6	9.6	7.1	5.3
WH-1105	68.4	49.2	35.5	19.8	14.4	10.6	53.0	34.1	20.4	15.6	10.2	6.3
Mean	**51.7**	**43.0**	**33.8**	**15.1**	**12.7**	**10.1**	**39.0**	**30.4**	**21.1**	**11.6**	**9.1**	**6.5**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 2. Mean table for fructose (mg/g dry wt.) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	10.5	8.2	6.1	3.9	3.2	2.6	8.3	6.1	3.8	3.2	2.5	1.8
C-306	12.8	10.1	6.8	4.7	3.8	2.8	9.6	7.2	4.2	3.6	2.9	2.0
DHTW-60	16.0	15.5	13.0	5.5	5.5	4.7	11.7	11.2	8.7	4.4	4.2	3.4
HD-2967	18.1	14.8	11.9	6.5	5.3	4.4	13.9	10.5	7.6	5.0	3.9	3.0
HTW-11	12.1	12.6	11.1	4.4	4.6	4.1	9.1	8.5	6.9	3.5	3.3	2.8
KUNDAN	14.4	11.4	8.5	5.2	4.2	3.3	10.3	8.0	5.2	3.9	3.2	2.3
WH-730	11.3	8.8	7.6	4.2	3.4	3.0	8.8	6.4	4.6	3.4	2.6	2.1
WH-1105	19.0	13.6	9.8	6.4	4.9	3.7	14.5	9.4	5.6	5.2	3.6	2.4
Mean	**14.3**	**11.9**	**9.3**	**5.1**	**4.4**	**3.6**	**10.8**	**8.4**	**5.8**	**4.0**	**3.3**	**2.5**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 3. Mean table for sucrose (mg/g dry wt.) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	47.4	37.0	27.2	14.2	11.2	8.4	37.4	27.0	16.7	11.3	8.3	5.4
C-306	58.4	45.8	30.4	17.3	13.7	9.3	43.4	32.1	18.5	13.0	9.8	5.9
DHTW-60	73.1	70.8	59.0	21.2	20.9	17.5	53.0	50.8	39.1	15.8	15.2	11.8
HD-2967	82.8	67.2	54.0	24.5	19.9	16.1	62.8	47.5	34.2	18.6	14.2	10.4
HTW-11	54.9	57.1	50.2	16.3	17.0	15.0	41.2	38.4	31.0	12.4	11.6	9.5
KUNDAN	65.7	51.6	38.2	19.4	15.4	11.5	46.4	36.1	23.2	13.9	11.0	7.2
WH-730	51.2	39.9	33.9	15.3	12.0	10.3	39.8	28.5	20.3	12.0	8.7	6.4
WH-1105	86.4	61.8	44.3	25.3	18.3	13.3	66.5	42.6	25.1	19.8	12.8	7.8
Mean	**65.0**	**53.9**	**42.2**	**19.2**	**16.0**	**12.7**	**48.8**	**37.9**	**26.0**	**14.6**	**11.5**	**8.0**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 4. Mean table for stem cell wall polysaccharide (cellulose, mg/g dry wt.) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	22.6	21.1	13.2	25.2	22.4	20.4	18.6	17.4	10.8	20.7	18.4	16.8
C-306	23.9	22.1	14.5	26.4	24.4	21.1	19.6	18.2	11.8	21.6	20.0	17.4
DHTW-60	25.4	24.8	17.9	27.5	26.9	25.3	20.8	20.3	14.5	22.5	22.0	20.8
HD-2967	26.1	24.3	17.5	28.7	26.3	24.8	21.3	19.9	14.1	23.4	21.5	20.3
HTW-11	23.3	23.2	16.8	26.1	25.4	23.8	19.1	19.0	13.6	21.4	20.8	19.5
KUNDAN	25.0	22.5	15.8	27.3	24.7	22.8	20.5	18.5	12.8	22.3	20.2	18.7
WH-730	22.9	21.5	15.5	25.6	23.5	22.5	18.8	17.7	12.6	21.0	19.3	18.5
WH-1105	26.6	23.6	16.5	29.0	25.6	23.5	21.8	19.4	13.4	23.7	21.0	19.3
Mean	**24.5**	**22.9**	**16.0**	**27.0**	**24.9**	**23.0**	**20.1**	**18.8**	**12.9**	**22.1**	**20.4**	**18.9**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 5. Mean table for water soluble carbohydrate (mg/g dry wt.) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	142.9	106.5	78.0	109.1	79.4	60.4	180.4	142.1	105.2	77.8	60.9	45.3
C-306	163.1	124.4	85.2	126.7	94.7	64.8	220.8	174.4	115.4	95.4	74.9	50.7
DHTW-60	203.3	191.9	161.4	152.1	148.4	124.3	274.0	267.4	222.0	119.3	115.4	96.8
HD-2967	235.3	176.8	142.0	178.4	139.7	111.0	297.7	251.0	204.4	135.8	108.8	88.5
HTW-11	157.2	147.2	131.7	121.4	112.3	101.2	208.2	214.2	188.5	89.7	93.9	82.8
KUNDAN	177.0	135.7	100.2	136.1	107.0	80.5	247.7	195.3	144.1	107.2	84.7	63.4
WH-730	152.9	114.6	89.6	116.1	84.5	71.3	195.2	150.4	129.4	83.7	65.7	56.3
WH-1105	250.0	159.1	107.9	188.0	125.6	84.7	324.3	230.1	165.7	143.2	100.9	73.4
Mean	**185.2**	**144.5**	**112.0**	**141.0**	**111.4**	**87.3**	**243.5**	**203.1**	**159.3**	**106.5**	**88.2**	**69.6**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 6. Mean table for sucrose synthase (units/mg protein) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	28.5	24.8	12.9	21.9	16.1	7.5	21.0	16.1	9.8	18.6	14.0	6.6
C-306	36.3	31.6	14.0	27.9	20.9	8.1	26.7	19.6	10.7	24.1	17.4	7.1
DHTW-60	44.1	46.0	20.5	34.0	30.7	12.4	33.1	29.8	15.7	28.8	26.0	10.5
HD-2967	48.6	42.1	18.5	37.4	28.0	11.2	36.6	28.0	14.1	31.7	24.3	9.5
HTW-11	34.5	36.8	17.4	26.6	24.4	10.5	25.9	22.7	13.1	22.2	20.0	9.0
KUNDAN	39.7	33.5	15.5	30.6	22.3	9.3	29.7	20.8	11.6	25.9	17.8	8.1
WH-730	32.3	28.8	14.8	24.9	18.7	8.9	23.8	18.2	11.2	21.3	16.2	7.6
WH-1105	51.7	39.0	16.5	39.9	25.6	9.9	39.0	25.3	12.6	33.7	22.0	8.4
Mean	**39.5**	**35.3**	**16.3**	**30.4**	**23.3**	**9.7**	**29.5**	**22.6**	**12.4**	**25.8**	**19.7**	**8.3**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 7. Mean table for invertase (units/mg protein) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	44.4	46.9	33.7	28.8	23.1	16.2	35.3	33.4	25.1	28.5	21.1	15.6
C-306	51.0	48.9	34.3	37.3	26.2	17.1	39.1	36.1	25.5	34.2	24.2	16.4
DHTW-60	53.2	53.6	39.4	42.0	33.6	23.1	40.5	38.0	28.5	35.7	24.5	17.7
HD-2967	55.4	52.9	38.9	42.9	32.4	22.6	41.6	37.3	28.1	34.8	26.3	19.0
HTW-11	50.5	50.8	37.7	32.4	28.6	20.8	39.1	36.6	27.8	32.0	21.7	19.7
KUNDAN	52.9	49.5	36.3	41.1	26.9	19.0	40.3	35.3	26.6	27.3	24.5	17.8
WH-730	47.6	47.4	35.8	31.8	24.2	18.4	37.2	33.9	26.9	29.0	22.5	17.2
WH-1105	57.8	51.3	37.3	44.2	29.4	19.7	43.0	37.1	27.4	33.9	27.5	15.6
Mean	**51.6**	**50.2**	**36.7**	**37.6**	**28.0**	**19.6**	**39.5**	**36.0**	**27.0**	**31.9**	**24.0**	**17.4**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 8. Mean table for starch branching enzyme (units/mg protein) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	15.7	16.7	11.9	10.2	8.3	5.6	14.0	14.9	10.6	8.3	6.7	4.1
C-306	18.1	17.3	12.2	13.3	9.3	5.9	16.2	15.4	10.9	10.8	7.5	4.3
DHTW-60	19.1	19.6	15.2	15.1	12.2	9.6	17.0	17.5	13.6	12.2	9.9	7.0
HD-2967	20.4	19.4	14.6	15.4	11.7	8.2	18.2	17.3	13.0	12.4	9.5	5.9
HTW-11	17.9	18.3	13.6	11.5	10.5	7.6	16.0	16.3	12.2	9.4	8.5	5.5
KUNDAN	18.8	17.6	12.9	14.7	9.6	6.7	16.8	15.7	11.5	11.9	7.8	4.9
WH-730	16.9	16.8	12.7	11.3	8.6	6.5	15.1	15.0	11.4	9.2	7.0	4.7
WH-1105	21.7	19.1	13.3	16.9	11.3	7.2	19.3	17.0	11.9	13.7	9.2	5.2
Mean	**18.6**	**18.1**	**13.3**	**13.5**	**10.2**	**7.2**	**16.6**	**16.1**	**11.9**	**11.0**	**8.3**	**5.2**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 9. Mean table for starch debranching enzyme (units/mg protein) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	6.2	5.8	3.6	12.3	10.0	6.5	4.4	3.6	2.3	7.9	7.4	4.7
C-306	8.2	7.2	4.1	13.2	12.3	7.2	4.7	4.4	2.6	10.5	9.2	5.2
DHTW-60	9.4	10.1	8.7	15.5	14.8	11.5	5.6	5.3	4.1	12.0	12.9	11.1
HD-2967	9.8	9.2	7.4	16.3	14.1	10.3	5.9	5.1	3.7	12.5	11.8	9.5
HTW-11	7.4	8.2	6.6	14.1	12.8	9.4	5.1	4.6	3.4	9.5	10.5	8.5
KUNDAN	8.8	7.6	5.0	14.9	11.4	8.2	5.4	4.1	2.9	11.3	9.7	6.4
WH-730	6.6	6.6	4.4	13.3	10.9	7.7	4.8	3.9	2.8	8.5	8.5	5.6
WH-1105	11.0	8.8	5.6	17.0	13.5	8.9	6.1	4.9	3.2	14.1	11.2	7.2
Mean	**8.4**	**7.9**	**5.7**	**14.6**	**12.5**	**8.7**	**5.2**	**4.5**	**3.1**	**10.8**	**10.1**	**7.3**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

Appendix 10. Mean table for ADP-glucose pyrophosphorylase (units/mg protein) in peduncle and penultimate internode at anthesis and 15 days after anthesis under timely, late and very late sown conditions

Genotypes	Peduncle						Penultimate internode					
	Anthesis			15 DAA			Anthesis			15 DAA		
	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS	TS	LS	VLS
AKAW-3717	6.9	5.3	4.6	4.8	3.6	2.3	6.0	4.7	3.7	2.3	1.2	0.7
C-306	7.7	5.6	4.1	5.3	3.9	2.2	6.6	4.9	3.5	2.9	1.4	0.6
DHTW-60	9.1	8.3	6.6	6.6	6.3	4.7	7.8	7.3	5.8	4.1	3.6	2.1
HD-2967	10.2	8.1	6.5	7.4	6.1	4.1	8.7	7.1	5.4	5.2	3.4	1.8
HTW-11	7.5	7.6	5.5	5.0	5.2	3.6	6.3	6.2	5.2	2.7	2.4	1.6
KUNDAN	9.1	5.6	4.6	6.2	4.0	2.8	7.6	5.0	4.0	3.9	1.5	0.8
WH-730	7.2	5.0	4.6	4.5	3.4	3.0	5.9	4.4	4.1	2.3	1.1	0.9
WH-1105	11.0	7.0	6.3	8.0	5.9	3.4	9.3	6.8	4.7	6.2	3.0	1.3
Mean	**8.6**	**6.6**	**5.4**	**6.0**	**4.8**	**3.3**	**7.3**	**5.8**	**4.5**	**3.7**	**2.2**	**1.2**

15 DAA= 15 days after anthesis, **TS=** Timely sown, **LS=** Late sown and **VLS=** Very late sown

ABSTRACT

Title of Thesis	:	**Studies on carbohydrate metabolism in wheat under drought and high temperature conditions**
Full Name of Degree Holder	:	KIRPA RAM
Admission No.	:	2013BS10D
Title of Degree	:	**Doctor of Philosophy**
Name and Address of Major Advisor:	:	Dr. (Mrs.) Renu Munjal Principal Scientist Department of Botany and Plant Physiology College of Basic Sciences and Humanities CCS HAU, Hisar-125004, India
Degree Awarding University	:	CCS Haryana Agricultural University, Hisar-125004, (India).
Year of Award of Degree	:	2017
Major Subject	:	Plant Physiology
Minor Subject	:	Plant Breeding
No. of Pages in Thesis	:	116 + xviii + V
No. of words	:	300

Key word: Drought, high temperature, wheat, physiological, biochemical and yield parameters.

(An abstract of the dissertation submitted to the CCS Haryana Agricultural University in partial fulfillment of the requirements for the degree of Ph.D.)

The present investigation was conducted to assess the effects of drought and heat stress conditions on carbohydrate accumulation and partitioning and identify physiological and biochemical traits related to accumulation and partitioning of carbohydrate under drought and heat stress conditions. The eight wheat genotypes (AKAW-3717, DHTW-60, C-306, HD-2967, HTW-11, WH-730 and WH-1105) in RBD with 4 rows of 2m length with a 20×5 cm spacing within rows and plants respectively, were grown during *rabi* season of 2015-16 and 2016-17 at Field Research Area, Wheat & Barley Section, Department of Genetics & Plant Breeding. Effect of individual drought and high temperature and their combination on physiological, biochemical and yield parameters under timely, late and very late sown condition was studied. Reduction in response of drought and high temperature was observed in physiological parameters (relative water content, osmotic potential, water potential, chlorophyll content, chlorophyll florescence taken in flag leaf) and biochemical parameters (peduncle and penultimate internode) at anthesis and 15 days after anthesis. Reduction in physiological and biochemical parameters was more pronounced under D40+D65 and complete drought at 15 days after anthesis as compare to anthesis. Metabolite (glucose, fructose, sucrose, water soluble carbohydrate and cellulose) and enzyme (SuSy, INV, SBE, SDBE and AGPase) activity get reduced under drought and with combination of delayed sowing. Fast rate of decline both in peduncle and penultimate inter node was observed. Yield was found highly associated with physiological and biochemical behavior of stressed plant. Yield penalty was more in combination of delayed sowing and drought situation at different growth stage. Genotype DHTW-60, HD-2967 and WH-1105 found promising in overall performance under timely, late and very late with different drought & high temperature situation. Carbohydrate metabolic & enzymatic traits with water relation & chlorophyll related traits are best traits for selection of drought and high temperature tolerant genotype.

MAJOR ADVISOR **SIGNATURE OF THE STUDENT**

HEAD OF THE DEPARTMENT

CURRICULUM VITAE

Name	**:**	KIRPA RAM
Date of birth	**:**	6-10-1989
Place of birth	**:**	Hisar (Haryana)
Father's name	**:**	Mr. Suraj Bhan
Mother's name	**:**	Mrs. Vidya Devi
Permanent address	**:**	V.P.O Mattershyam, Hisar (HRY) 125001 (Dhani near bus stand)
Mobile	**:**	+91-94683-93474 +91-97282-47326
E-mail	**:**	dr.kirparamjangra@gmail.com dr.kirparamjangra@hotmail.com

Academic qualifications

Degree	University/Board	Year of passing	%age of marks	Subjects
10+2	BSEH	2007	51.00	Hindi, Eng., Physics Chemistry, Biology
B.Sc.	KUK, Kurukshetra	2010	52.55	Chemistry, Botany, Zoology
M.Sc.	CCS HAU, Hisar	2013	68.00	All major Plant Physiology subjects
Ph.D.	CCS HAU, Hisar	2017	71.30	All major Plant Physiology subjects

Co-curricular activities : **2nd Prize** in inter college Kabaddi competition
Second prize in plant quiz competition and on spot poster making in chrysanthemum flower show held in Botanical garden of CCS Haryana Agricultural University January 6-4, 2014.

Research paper

Kirpa Ram., Munjal, R., Sunita., Pooja. & Kumar, N. (2017) Evaluation of chlorophyll content index and normalized difference vegetation index as indicators for combine effects of drought and high temperature in bread wheat genotypes. *Global journal of Bio Sciences & Biotechnology*, **6(3)**, 528 – 537.

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(Kirpa Ram)

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I, **Kirpa Ram**, Admn. No. **2013BS10D** undertake that I give copyright to the CCS HAU, Hisar of my thesis entitled, **"Studies on carbohydrate metabolism in wheat under drought and high temperature conditions".**

I also undertake that patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCS HAU, Hisar.

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