PHOTOSYNTHETIC EFFICIENCY AND NUTRIENT UPTAKE IN WHEAT GROWN UNDER TIMELY, LATE AND VERY LATE SOWN CONDITIONS

BY
BHARTI RAWAL
(2019BS34M)

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

MASTER OF SCIENCE
IN
PLANT PHYSIOLOGY

DEPARTMENT OF BOTANY AND PLANT PHYSIOLOGY
COLLEGE OF BASIC SCIENCES AND HUMANITIES
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR – 125004

2022

CERTIFICATE-I

This is to certify that this thesis entitled, **“Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions”** submitted for the degree of **Master of Science** in the subject of **Plant Physiology** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Ms. Bharti Rawal** Admn. No. **2019BS34M** under my supervision and guidance 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. Anita Kumari
(MajorAdvisor)
Assistant Plant Physiologist
Deptt.of Botany and Plant Physiology
College of Basic SciencesandHumanities
CCS HaryanaAgricultural University
Hisar-125004 (Haryana), India

CERTIFICATE-II

This is to certify that this thesis entitled **"Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions"**, submitted by **Ms. Bharti Rawal** Admn. No. **2019BS34M** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirement for the degree of **Master of Science** in the subject of **Plant Physiology**, has been approved by the Student's Advisory Committee, after an oral examination on the same.

MAJOR ADVISOR **EXTERNALEXAMINER**

HEAD OF THE DEPARTMENT

DEAN, POST-GRADUATE STUDIES

CERTIFICATE – III

It is certified that the thesis submitted by **Ms. Bharti Rawal**, Admn. No. **2019BS34M**, a M.Sc. student of **Department of Botany and Plant Physiology** has been checked and found as per specification of the format circulated by Dean, PGS vide Memo. No. PGS/A-1/09/6926-90 dated 26/8/2009.

MAJOR ADVISOR

PROFESSOR AND HEAD
DEPARTMENT OF BOTANY AND PLANT PHYSIOLOGY

ACKNOWLEDGEMENT

A precious debt as that of learning is the only debt that is not only difficult but also impossible to repay except perhaps through gratitude. I would like to memorize and thank the people who were instrumental in the completion of this important milestone of my academic pursuit. Although "thanks" is a poor expression of the deep sense of gratitude one feels in the heart, yet there is no better way to express ones sentiments. My thesis will be undone without expressing my feeling which cannot be moulded into words from the core of my heart.

I feel immense pleasure in expressing my deep esteemed sense of perfumed gratitude with reverence to my Major Advisor ***Dr. Anita Kumari****, Assistant Plant Physiologist for her encouragement and moral support showed on me and inspiring guidance, scientific proficiency, constructive criticism, constant encouragement, scholarly guidance and whole hearted cooperation during my entire study and assistance rendered during the preparation of the thesis.*

I truly appreciate the most kind hearted and mentally strong person for her valuable suggestions, everlasting help and ever-encouraging attitude of ***Dr. Vinod Goyal****, Assistant Plant Physiologist, Department of Botany and Plant physiology (Member from Major Subject) and also sincere thanks to others worthy members of my advisory committee,* ***Dr. Shiwani Mandhania****, Assistant Biochemist,Cotton Section, Deptt. of Genetics and Plant Breeding (Member from minor subject),* ***Dr. Sarita Rani*** *Assistant Professor (Statistics) Deptt. of Mathematics and Statistics (Member from supporting subject) and* ***Dr. Satbir Singh Jakhar*** *ASRO (Plant Pathology) Deptt. of Seed Science and Technology (Dean, PGS Nominee) for their valuable suggestions, everlasting help and ever-encouraging attitude. Distinctive words of thanks are due to,* ***Dr. Renu Munjal*** *Principal Scientist (Plant Physiology) for giving me guidance and moral support during my research programme and in necessary times. My sincere thanks goes to* ***Dr. Sarita Devi****,* ***Dr. Babita Rani,*** *who really helped me a lot in necessary times during my research programme. I also thanks to* ***Dr.Neeraj Kumar****, Professor and Head, Deptt. Of Botany and Plant physiology for providing the necessary facilities and cordial help whenever required.*

It is my pleasure to express sincere thanks to all the non-teaching staff for their untiring help during the research work.

I am also thankful to my seniors Pooja Ahlawat, Kiran, Sarita, Priyanka, Sinky, Sapna and Neelam for the co-operation in research work and my classmates P.S. Kiran, Bhupnesh Sharma and Gayatri Kumari who impelled and helped me in the entire course of study and research work. Each moment shared with them is like pearls in thread to me I can count them again and again.

The words can hardly express the ardent sentiments of my feelings of indebtedness to the most beautiful and dearest person of my life, my respected parents, ***Sh. Dinesh Kumar*** *and* ***Smt. Sunita Devi*** *whose worthy counsel, affectionate blessings and moral inspiration have always created confidence in me to complete this work and I would also like to express my love towards the tinkling stars of my life, my brothers and sisters.*

Last but not the least, I am thankful to all those who helped me directly or indirectly and whose name could not be mentioned, they will always remain in my heart.

The warmth showered upon me through every handshake, every smile and many a times through unsaid words is warmly acknowledged.

Dated: July, 2022 **(Bharti Rawal)**
Place: Hisar

CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

&	: and
°C	: Degree Celsius
µM	: Micro molar
A	: Photosynthetic rate
CCI	: Chlorophyll Content Index
cm	: Centimeter
CT	: Canopy temperature
CTD	: Canopy temperature depression
DAA	: Days after anthesis
DAS	: Days after sowing
DH	: Days to heading
DM	: Days to maturity
E	: Transpiration rate
et al.	: et. alia (and others)
g	: gram
gs	: Stomatal conductance
HSI	: Heat susceptibility index
i.e.	: that is
LS	: Late sown
mM	: Mili molar
No.	: Number
PH	: Plant height
SL	: Spike length
SPAD	: Soil plant analysis development
TS	: Timely sown
viz.	: *videra licet* (namely)
VLS	: Very late sown

CHAPTER-I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the major cereal crop which contributes about 30 % of world grain production and 50 % of the world grain trade (Akter *et al.*, 2017).Wheat belongs to family *Poaceae* commonly known as grass family. It is grown in rabi season. Being a staple food for over 36 % of the world population, wheat fulfills the protein and caloric needs of one third world's population (Khan and Mohammed, 2018). It is an elegant source of nutrients and energy containing major constituents of the food i.e., vitamins particularly riboflavin, thiamine, niacine and vitamin E. Wheat is enriched by protein and carbohydrates and vital minerals such as phosphorus, magnesium, copper, iron, and zinc (Bhanu *et al.,* 2018). Wheat is cultivated under different environmental condition ranging from humid to arid, subtropical to temperate zone (Saari EE, 1998).

In the world, wheat has the biggest acreage of all crops, occupying over 217 million hectares worldwide, with an annual production of around 731 million tonnes (Miransari and Smith, 2019). In India, blessed with a diverse agro-ecological environment, wheat has given food and nutrition security to the majority of the Indian population, particularly in recent years, through production and steady supply. India is the world's second-largest producer, with a wheat-growing area of 31.4 million hectares (14.65 % of the global area), a production of 107.6 million tonnes (14.64 %), and productivity of 3421 Kg/ha, trailed only by China (Raza and Santella, 2020). In India it is grown mostly in the plains whereas in the hills it is cultivated in mountainous region of north India and Nilgiris and Palani hills in South India. Wheat is grown in most of the Indian states excluding Southern and North Eastern states, with Uttar Pradesh, Punjab, Haryana, and Rajasthan being the leading producers. Over the last five years, Haryana has been the fourth greatest wheat producer, with an average area, production, and productivity of 2.3 million hectares, 9.3 tonnes, and 4 tonnes/ha, respectively (ICAR-IIWBR, 2020).

Wheat production has declined by 5.7 percent in the nearly stable area of its cultivation over the last five years (https://icar.org) due to climate change also the global human population is predicted to grow by 25% over the next 30 years, reaching 10 billion people. Currently, roughly 820 million people out of a population of 7.75 billion are hungry, and global population is expected to rise to 9.7 billion by 2050 (FAO 2021). To satisfy the demands of a growing population, global wheat productivity must be raised. However, wheat productivity is controlled by a variety of factors including planting date, fertilizer use biotic and abiotic conditions such as temperature, salt, and drought.

Among various factors responsible for low yield of wheat crop in the country, late sowing of wheat is one of the major reasons of the yield reduction. Wheat is a themo-sensitive long day crop and sown in winter. It has its own definite requirement for temperature and light emergence, growth and flowering (Dabre *et al.,* 1993). Sowing at an appropriate time is one of the most vital conventional measures in increasing grain yield of winter wheat, which often facilitates the fast growth of plants. Wheat is commonly sown in India from November to late December, depending on the weather, topography, and harvesting of kharif crops. Because of the late harvest of previous crop wheat has a shorter crop period (Nishio *et al.*, 2013). As a result, a portion of the maturity period of the crop is pushed forward and thus has to face higher temperature of the summer as well as hot spells often occurring at that time. Sowing date is one of the major factors which determine the ability of the crop to stand against different environmental conditions (air, temperature, humidity). Under late sown condition wheat crop faces low temperature in the earlier part and high temperature in the later part of the growing season. The crop requires favorable moisture for better growth and development but rains during April which may reduce grain quality. In late planting the wheat variety should be of short duration that may escape from high temperature at the grain filling stage (Phadnawis and Saini, 1992). All of wheat's growth stages are often slowed down by high temperatures, but the vegetative and reproductive stages are particularly affected. High temperature stress dramatically reduces the amplitude of sink components throughout the vegetative stage, such as culm length, spike length, and duration from heading to maturation. Krupnik *et al.* (2015) reported that early sowing caused wheat to escape heat stress, as the late sowing takes wheat growth into a period during which higher temperatures are experienced, resulting in terminal heat stress and yield loss. Particularly when it happens during the reproductive and grain-filling stages, heat stress is particularly harmful (Hays *et al.,* 2007; Farooq *et al.,* 2011).

Heat stress affects photosynthetic capacity of plants (Wahid *et al.,* 2007), creates metabolic restrictions (Farooq *et al.,* 2011), encourages the formation of reactive oxidative species (Wang *et al.,* 2011), decreases the growth of pollen tubes and results in pollen mortality (Saini *et al.,* 2010), enhances ethylene production and therefore increasing grain abortion (Hays *et al., 2007).* Wheat plants sustain more damage during the reproductive stage than during the vegetative stage because it has a direct impact on the number and weight of the grains (Wollenweber *et al.,* 2003). Heat stress, also known as terminal heat stress, is most severe during the grain filling stage, which is when wheat is produced (Wahid *et al.,* 2007). There are 36 Mha of wheat reported to be in terminal heat stress globally (40 % of the temperate environment) (Hays *et al.,* 2007). A major effect of heat stress is the reduction in photosynthesis because of decreased leaf area expansion, premature leaf senescence and associated reduction in wheat production (Ashraf and Harris, 2013, Mathur *et al.,* 2014). Heat stress causes a reduction in total chlorophyll content and chlorophyll fluorescence by disruption of structure and function of chloroplasts (Shanmugam *et al.,* 2013). The inactivation of chloroplast enzymes, mainly induced by oxidative stress also reduces the rate of leaf photosynthesis. Study of Agarwal *et al.* (2021) reported that, when crops are seeded late, both photosynthesis and stomatal conductance significantly decline, while heat-tolerant genotyopes continue to sustain higher rates of both processes post-anthesis. Transpiration rate is an important parameter which is directly linked with temperature sensitivity Vis a Vis water availability for a plant. In comparison with ambient temperature, elevated temperature causes higher transpiration rates (Khan *et al.,* 2020). Cell membrane thermal stability, canopy temperature depression, stomatal conductance and photosynthetic rate are all physiologically vital under heat stress (Reynolds and Rebetzke, 2011). Increase in temperature from 22 to 32 °C caused decrease in photosynthesis rate and transpiration (Zhang *et al*., 2010). Increasing severity of heat stress from heading to maturity is a major concern in cooler northern wheat-growing regions (Liu *et al.,* 2014). Yield loss of 33.6 % was observed in major wheat cultivars due to heat stress in late sown conditions indicates that there is a need to incorporate heat tolerance in wheat cultivars to achieve sustainable production (Chatrath *et al.*, 2007; Joshi *et al*., 2007). Taking into account the above facts, the present investigation entitled “**Photosynthetic efficiency and nutrient uptake in wheat grown under timely late and very late sown conditions''** was planned with the following objectives:

1. To evaluate the photosynthetic efficiency and nutrient uptake in wheat genotypes
2. To find correlation between photosynthetic efficiency and nutrient uptake with high temperature tolerance

CHAPTER-II

REVIEW OF LITEATURE

After rice, wheat (*Triticum aestivum* L.) is the second most important staple crop in the world. It is renowned as the "King of cereals." It is an annual, monocot, C_3 and cool season crop. It is a winter crop with an upright growing habitat. In its natural condition, it is an excellent source of protein, fibre, manganese, and magnesium. Due to its increased flexibility and resilience under a variety of agro-climatic conditions, its area and yield are expanding fast over the globe (Kumar *et al*., 2014). It may be produced as a dual-purpose crop that maximises the value of both seeds/grains and feed sown on the same field (Shuja *et al*., 2010).

The growing worldwide population has increased the need for wheat production. In the approaching years, its production rate must be enhanced to meet the food demands of a growing population (Tilman *et al*., 2011). Various biotic and abiotic stressors are also the primary drivers of agricultural production decline (Wani and Sah, 2014). Wheat is vulnerable to increasing temperatures (Akter and Rafiqul, 2017). At the end of the 21st century, the global climate model predicts that the average temperature would rise by 60 °C (De Costa, 2011). Heat stress induces morpho-physiological changes in wheat plants, impeding their growth and ultimately resulting in substantial yield loss (Lin *et al.,* 2019). Thus, high temperature stress is one of the most critical factors limiting wheat productivity. India is a subtropical, tropical, and temperate nation with a mean annual temperature of 25 °C, which is projected to increase by 0.21 °C by 2050 (Karmakar and Shrestha, 2000). As a result of late sowing, high temperatures during the reproductive stage and grain filling are one of the leading reasons of yield loss in late-sown wheat. During the reproductive phase of a plant's growth, it is subject to high temperatures (Singh *et al*., 2015). Consequently, there is an urgent need to catalogue the genetic diversity that aids in adaptations to the coming warmer climatic circumstances of the future and aids in the development of novel cultivars that can tolerate such heat stress conditions. Under the following headings is a brief summary of the study performed for our current study entitled "Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions"

2.1 Implications of heat stress on wheat

Wheat is a temperate cereal crop that requires a temperature range between 12 and 20 degrees Celsius for optimal growth of its reproductive phase (Al-khatib and Paulson, 1999; Farooq *et al*., 2011). Consequently, crop development and production are greatly impacted by an increase in temperature over the optimal level, which is responsible for heat stress in crops (Wahid *et al*., 2007; Farooq *et al*., 2011). Heat stress negatively impacts every developmental stage of wheat (Cossani and Reynolds, 2012), although the reproductive developmental phase is more vulnerable (31-40ºC) by significantly affecting floral fertility, grain number, grain weight, and grain yield (Ferris *et al*., 1998; Wollenweber *et al*., 2003; Semenov, 2009). High temperature alters numerous morpho-physiological aspects of wheat plant, such as photosynthesis (Salvucci and Crafts-Brander, 2004; Ristic *et al*., 2007), pollen viability (Saini and Aspinall, 1982), starch synthesis (Zhao *et al.*, 2008), grain filling period (Dias *et al*., 2008; Dias *et al*., 2010), stem solidity (Pierre *et al.* (Wang *et al.*, 2011). This is dependent on developmental stage (Dias and Lindon, 2009; Wang *et al.*, 2011) and genotype (Dias *et al.*, 2010). Fischer (1985) and Ortiz *et al.* (2008) observed that high temperatures 20 days prior to and 10 days after anthesis reduced the amount of grains. The decline in grain number around anthesis is attributable to the effect of high temperature on pollen fertility or sterile grains, which considerably increased between 27 and 31ºC around mid-anthesis. The following table illustrates the wheat crop's temperature sensitivity in relation to its developmental stages.

Table 2.1: **Response of phasic development to temperature**

Developmental phase	**Temperature Sensitivity**
Germination	Strong
Canopy development	Moderate/strong
Spikelet production	Slight/moderate
Spikelet development	Moderate/strong
Grain development	Moderate/strong

(Source: Slafer and Rawson, 1994)

2.2 Morphological and phenotypic characteristics

The phenology of a crop plant is influenced by the sowing date, high temperatures during anthesis, and grain filling. Temperature plays a vital role in all phases of wheat growth. High temperatures accelerate plant development and shorten the duration of all phases, resulting in fewer days for assimilate accumulation during the plant's life cycle and a decrease in output (Fischer and Maurer, 1976). Kumar *et al.* (2016) determined that wheat required 100-110 days of favourable winter to produce its maximum yield. Under conditions of late sowing, plant height decreases significantly (Tewari, 1990; Kumar *et al.*, 2016). Similarly, Ahemed and Farooq (2013) demonstrated a 32.54 percent drop in plant height under late sowing conditions, although no significant variations were seen under regular sowing conditions. Irfaq *et al.* (2005) similarly observed that late planting and severe temperature stress reduced the plant height of wheat genotypes. Sial *et al.* (2005) observed that the delay in wheat planting considerably affects the heading time of genotypes. Days before heading demonstrated a considerable increase in heat stress compared to normal sowing. Similarly, Hakim *et al.* (2012) reported a 14-19% reduction in the number of days to heading in wheat genotypes due to delayed sowing. However, Chaudhary (2004) reported that the number of days to heading was not affected by delayed sowing, but that heat stress decreased the number of days to maturity in late-sown crops. According to Tewolde *et al.* (2006), early heading is a beneficial characteristic characterising wheat cultivars that are tolerant to heat stress during the post-heading phase. Rezaei *et al.* (2015) reveal a significant correlation between the average spring temperature and the day of heading (DOH) of winter wheat. Regardless of wheat genotype, heat stress affects spike length. The loss in spike length under high temperature stress varies from 33.3 to 22.3 (Dwivedi *et al.*, 2017). Kumar *et al.* (2016) reported a significant decrease of 27.05 percent in spike length. Heat stress during the reproductive phase inhibits spike growth and stimulates reproduction phase force development. The inhibition of cell division and cell elongation influences spike length (Punia *et al.*, 2011).

Under conditions of late sowing, plants reach early maturity because warmth accelerates plant development and shortens the phases of plant development. Under late sowing conditions, wheat genotypes exhibited a considerable decrease in maturation duration. Ahmed *et al.* (2013) found a mean decrease of 17% for this characteristic. Similarly, Nahar *et al.* (2010) observed that heat stress might shorten the maturation period of wheat genotypes by up to 15%. Early-maturing wheat lines have considerable yield potential for enhancing wheat output (Mondal *et al.*, 2016). Mohammadi *et al.* (2004) and Islam *et al.* (2011) showed a decrease in plant height when sowing was delayed. In late-sown wheat, plant height was lowered by 25.8 percent (Hamam, 2013). The growth and development of plant organs, as well as the source-to-sink transfer, were significantly impacted by delayed crop seeding, as seen by a reduction in plant height and days to maturity (Singh *et al.*, 2011). Temperature has a significant impact on the phenology of wheat crops. Crop sowing timing has an effect on days to heading and days to maturity. Chaudhary (2004) showed a reduction in days-to-maturity for crops grown late. Tewolde *et al.* (2006) indicated that early heading is an effective characteristic determining wheat cultivars' tolerance to heat stress during the time after heading. Rane *et al.* (2007) observed that a delay in seeding decreased the duration of the crop cycle, which eventually led to a decrease in biological yield due to a shorter grain filling time. Hamam (2013) reported a decrease in the duration of developmental phases in late-sown wheat as a result of high temperature stress. The duration of the growing season is directly affected by high temperature. Increasing the temperature above the optimal lowers the time of grain loading. Begum and Neesa (2014) found that among wheat genotypes, the crop duration for Shatabdi, Bijoy, and Prodip under timely sowing conditions was 99, 99, and 98 days, respectively. They decreased to 95, 88, and 95 days when the temperature rose to 28°C, and to 81, 76, and 81 days, respectively, at 35°C. Bijoy saw the greatest drop in crop growth time, indicating that it is the most vulnerable variety to heat stress. Shah *et al.* (2006) noticed a decrease in wheat heading days under LS conditions. The most days to heading were recorded on the 16th of November (197.08) and the least on the 16th of January (72.33).

Under conditions of late sowing, plants reach early maturity because warmth accelerates plant development and shortens the phases of plant development. Under late sowing conditions, wheat genotypes exhibited a considerable decrease in maturation duration. Due to the influence of heat stress, Nahar *et al.* (2010) showed a 15 percent reduction in the maturation duration of wheat genotypes. Jangid and Srivastava (2018) found that under normal sowing conditions, a crop matures in around 118 days, however under late and extremely late sowing conditions, it matures in approximately 106 and 93 days, respectively.

2.3 Physiological characteristics

2.3.1 Canopy temperature:

Canopy temperature is a non destructive monitoring parameter of whole plant used to assess the plant response to different environmental stresses including high temperature stress (Munjal and Rana, 2013). The canopy temperature is a direct measurement of evaporation or transpiration from the leaf surface and has a significant relationship with stomatal conductance (Rebetzke *et al.*, 2008). Canopy temperature had a key role among physiological variables because of its favourable relationships with grain yield per plant, grain yield per spike, and biomass (Roohi *et al.*, 2015). The decrease in canopy temperature 15 days after anthesis was discovered to have a substantial positive link with grain production under timely seeded conditions as opposed to late sown ones (Saxena *et al.*, 2016). Reynolds (2002) suggests that a low CT may be symptomatic of a strong need for photoassimilation due to quickly filled kernels. Canopy temperature is an indication of the stomatal conductance of a plant throughout time (Pfeiffer *et al.*, 2005), plant water relations, deep roots, and production (Reynolds *et al.*, 2012). Higher CT suggests stomatal closure because of decreased transpiration, and vice versa. A low CT, on the other hand, is indicative of a plant's ability to tap fluid from lower soil layers, therefore satisfying the transpiration needs imposed by hot weather conditions in the plant's micro environment. In the research, the association between CT and yield is consistently negative in both drought and heat situations, and a cooler canopy confers a yield advantage under stress (Reynolds *et al.* 1994; Gutierrez *et al.* 2010; Pinto *et al.* 2010). Canopy temperature measures were positively connected with yield at international durum wheat locations, where CT levels increased with cultivar release date and yield (Giunta *et al.* 2008). It is reliant on a variety of environmental conditions, including soil water condition, humidity, and radiation; hence, a lack of connections may be attributed to the interplay of environmental elements in the varied site. Genotypic variation for CT in wheat has been documented by (Ayeneh *et al.* 2002; Karimizadeh and Mohammadi, 2011). Higher grain weight and a cooler canopy under heat stress during grain filling are indicators of heat tolerance (Tyagi *et al.*, 2003; Singha *et al.* 2006). (Gabaldón-Leal *et al.*, 2016) Canopy temperature permits more precise estimations of heat stress on the crop and its production. Under field conditions, canopy temperature can differ from air temperature due to the interaction between plant characteristics, plant water availability, air temperature and humidity, solar radiation, wind speed, and the resulting canopy microclimate (Michaletz *et al.*, 2016).

Gautaum *et al.* (2015) evaluated 102 wheat germplasm under late and extremely late sowing circumstances and found a substantial negative association between CT and grain production and biomass. According to Reynolds (2002), a high canopy temperature depression (CTD) may be symptomatic of a strong demand for photoassimilation in physiologically well-adapted lines due to rapid grain filling. The genotypes with low CT, including hexaplod genotypes of Triticale and Pishgam (bread wheat genotype), exhibited high grain yield (112 gm^{-2}) indicating that the cooler canopy should have resulted in improved adaptability to drought stress (Roohi *et al.*, 2015). Ray and Ahmed (2015) discovered low CTD in four genotypes eight and thirty-two days after germination under late-sown conditions. In contrast to genotypes Pavon 76 and BAW 1135, genotypes BARI gom 26 and BARI gom 25 retained a greater CTD under heat-stressed conditions. According to Mohammadi *et al.* (2012), selection for low CT during heat stress can increase yield, but high CT can be utilised to exclude lines with extremely poor yield under heat stress. Ayeneh *et al.* (2002) showed that the temperature of the canopy is affected by a number of physiological processes, including stomatal conductance, crop water use efficiency, and leaf area index. Less CT during the time of grain filling in wheat is a crucial physiological trait for high-temperature stress resistance (Munjal and Rana, 2003). Therefore, this is a crucial instrument for identifying genotypes resistant to hot and dry environmental circumstances (Reynolds *et al.*, 2009)

2.3.2 Photosynthetic rate

Photosynthesis is the most temperature-sensitive physiological function (Wahid *et al.*, 2007), and any loss in photosynthesis impacts wheat's development and grain output (Ali *et al.*, 2010). Under stressful conditions, the decrease in photosynthesis has been related to both stomatal and non-stomatal restrictions (Misson *et al.*, 2010). Stomatal closure prevents CO_2 from migrating to sites of carboxylation, hence causing stomatal restriction in photosynthesis. Wheat photosynthesis rates are ideal around 25 °C (Yamasaki *et al.*, 2002), and it decrease when the temperature deviates from this point. According to Singh *et al.* (2017), under increased temperatures, photosynthetic rates decreased much more than under ambient conditions during the grain filling stage. Schapendonk *et al.* (2007) demonstrated that heat shock during 'grain filling' reduced photosynthetic rate. The rate of leaf photosynthesis was reduced by 40 to 70 %, depending on cultivar and stage of development. Durum wheat's photosynthetic performance indicates a strong resistance to heat stress (Dias *et al.*, 2010; Gautam *et al.*, 2014). At the seedling and maturity stages, high temperatures lowered average photosynthetic rates by 32 and 11 percent, respectively. High temperatures reduce wheat yield by impairing photosynthetic rate and viable leaf area during maturity (Shah and Paulsen, 2003). According to Saxena *et al.* (2016), in conditions of late sowing and high temperature, the rate of photosynthesis decreases dramatically. Under timely sowing conditions, the rate of photosynthesis was much greater in genotypes, but it was low under late sowing conditions. Heat stress reduced chlorophyll concentration and net photosynthetic rate in plants (Todorov *et al.*, 2003). Pooja (2017) examined photosynthetic rate of 20 wheat genotypes at various grain filling stages under terminal high temperature conditions. She discovered that genotype WH1021 had the highest photosynthetic rate (16.95, 14.24, and 9.12) at 7, 14, and 21 days after anthesis (DAA), respectively. Hasanuzzaman *et al.* (2013) revealed that heat stress modifies plant water relations, hence decreasing photosynthetic effectiveness. Gupta *et al.* (2015) observed that RAJ4083 maintained a greater photosynthetic rate and stomatal conductance than other genotypes at anthesis and 15 DAA under timely planted conditions compared to late sown conditions. Under heat stress, Arfan *et al.* (2007) reported a strong link between yield and photosynthesis in durum wheat.

2.3.3 Rate of transpiration

Important metric directly related to a plant's temperature sensitivity and water availability is its transpiration rate. The transpiration rate was shown to be greater at increased temperatures than at ambient conditions (Singh *et al.*, 2017). It was suggested that increased transpiration may assist heat-tolerant genotypes in sustaining a greater photosynthetic rate through a cooling impact. Temperature increase from 22 to 32 degrees Celsius decreased photosynthetic rate and transpiration (Zhang *et al.*, 2010). Gupta *et al.* (2015) reported that under conditions of heat stress, the transpiration rate decreased. The heat-tolerant wheat genotype RAJ4083 maintained the maximum transpiration rate, which in turn maintained a greater photosynthetic rate via a cooling effect. Even under abiotic stressors, Ahmed *et al.* (2012) found that Wafaq-2001 had the highest transpiration rate and the lowest yield, whereas NARC-2009 and Tatara had lower transpiration rates and greater yields. In a study done by Feng *et al.* (2014), heat increased the rate of transpiration in winter wheat. Sunita *et al.* (2017), Pooja and Munjal (2019), and Khan *et al.* (2019) observed a significant reduction from timely to late sowing circumstances for the transpiration rate during anthesis in wheat crop.

2.3.4 Stomatal conductance

Stomatal conductance quantifies a leaf's rate of gaseous exchange and transpiration (Pietragalla and Pask, 2012). Stomatal conductance is a significant characteristic that affects yield under stressful conditions. Multiple studies have demonstrated that stomatal conductance is an additional selection criterion for crop stress resistance (Dodd, 2003; Koc *et al.*, 2008). Increased stomatal conductance during grain filling is believed to be the fundamental criterion for high grain production under stressful conditions (Munjal and Rana, 2003). The association between wheat stomatal conductance and grain yield was found to be non-significant (Anjum *et al.*, 2008). Elmetwalli *et al.* (2012) identified high connections between several sensitivity indices and different wheat qualities during the grain filling phases. In general, stomatal conductance decreased as crop maturity progressed. Singh *et al.* (2017) showed a greater stomatal conductance at increased temperatures than at ambient temperatures. Compared to their respective controls, heat stress increases stomatal conductance by 7.09 percent in heat-tolerant cultivars and by 23.67 percent in heat-sensitive cultivars. At 10 DAS, 10 days after 3 days of heat stress, the stomatal conductance of flag leaves of a heat-sensitive cultivar was considerably lower than it had been prior to stress (Feng *et al.*, 2014). Stomatal conductance can change with short term changes in photosynthetically active radiation and temperature (Squire and Black, 1981). Depending on the genotype, it also varies with seasonal and daily variances in plant water relations. Bahar *et al.* (2009) discovered a correlation between genotypes stomatal conductance, grain quantity per spike, and spike length at early milky maturity, but a negative correlation with plant height during the grain filling stage. Under high temperatures, Ahmed *et al.* (2012) discovered that stomatal conductance and grain production were substantially connected. The principal advantage of increased stomatal conductance was the increased transpiration rate (Munjal and Dhanda, 2004). Belay *et al.* (2021) found substantial connections between bread wheat's yield-attributing characteristics and stomatal conductance. Pooja and Munjal (2019) showed that the stomatal conductance of several wheat genotypes reduced by 19.0 to 47.10 percent from anthesis to 14 DAA. Agarwal *et al.* (2021) discovered that photosynthesis and stomatal conductance reduced dramatically under late seeded conditions, but the heat tolerant genotype maintained a greater rate of photosynthesis and stomatal conductance following anthesis under late sown conditions. The principal advantage of increased stomatal conductance was the increased transpiration rate (Munjal and Dhanda, 2004). Thus, stomatal conductance is a helpful selection criterion for wheat yields produced at temperatures above optimum.

2.3.5 Chlorophyll content (SPAD)

For nutrition management, a chlorophyll metre is a non destructive or simple device that may be used to assess the greenness, relative chlorophyll content, or nitrogen content of leaves at different stages of growth (Jhanji and Sekhon, 2017). Changes in chlorophyll concentration are indicative of the tolerant and vulnerable character of genotypes under intense light, high temperature, and dry air conditions in cultivars planted early and late (Pooja and Munjal, 2019). In heat stress conditions, there is a decrease in total chlorophyll content, which is correlated with a decrease in photosynthesis, which leads to a reduction in antenna size and, ultimately, a decrease in light harvesting (Shanmugam *et al.*, 2013). High temperature damages photosynthetic membrane and causes chlorophyll loss as a result of decreased production and increased loss (Tiwari and Tripathy, 2012). Stay-green plants exhibited steady chlorophyll concentration and a high Fv/Fm ratio (Vijayalakshmi *et al.*, 2010). Maintaining high chlorophyll content in wheat is an advantageous characteristic in breeding for heat tolerance, since it results in a low degree of photoinhibition at high temperatures (Ristic *et al.*, 2007; Talebi, 2011). Sangwan *et al.* (2018) found that genotype WH 1021 had the highest chlorophyll content under TS and LS conditions (32.7, 31.5), whereas WH711 had the lowest (28.6, 24.6). Islam *et al.* (2014) found a favourable correlation between SPAD levels and grain yield at distinct development phases, namely 70 and 96 DAS. Khan *et al.* (2015) demonstrated a strong negative link between chlorophyll content of flag leaf and canopy temperature and grain filling rate at anthesis and 21 DAA, however a positive correlation was observed with grain filling period. Dhyani *et al.* (2013) found that the chlorophyll content of PBW-574, K-0-307, and HS-240 genotypes was lower under late-sown conditions (38.90, 44.73, and 40.00) than in timely-sown conditions (34.50, 41.52, and 37.00) after 90 and 110 days.

2.3.6 The fluorescence of chlorophyll (Fv/Fm)

The fluorescence of chlorophyll is measured with a fluorometer. Chlorophyll pigment damage enhances fluorescence. A saturating flash of light boosts the fluorescence from its base value (F_O) to its maximum (Fm). Quantum efficiency of Photosystem II (PSII) is computed using the formula Fv/Fm, where Fv = (Fm-Fo). Temperature affects thylakoid-related processes, modifying the amount of absorbed light energy transduced from photosystem II (PSII) to photosystem I (PSI) and, therefore, the fluorescence pattern of chlorophyll (Sheikh *et al.*, 2010). Fluorescence is a useful technique because it provides information on the structure and function of PSII. This approach of evaluating PSII photochemistry in cultivars is significant because it provides fresh insights into the fundamental mechanisms of energy absorption, surplus excitation energy use, and dissipation by PSII in cereal crop plants (Antelmo *et al.*, 2010). Chlorophyll fluorescence was utilised to assess heat-induced suppression and recovery of PS-II in field-grown wheat in order to evaluate photosynthetic activity and peroxidation of thylakoid lipids during heat-induced photo inhibition in isolated wheat chloroplasts (Mishra and Singhal 1993; Park *et al.*, 1994; Dash and Mohanty, 2001). Zivcak *et al.* observed a linear association between carbon dioxide assimilation efficiency and real PS-II efficiency as determined by chlorophyll fluorescence quenching study (2009). The decrease in maximum quantum efficiency of photochemistry (Fv/Fm) demonstrates that heat stress generated by temperatures over 40°C had a major impact on fundamental photosynthetic processes. Efeoglu and Terzioglu (2009) evaluated the high-temperature photosynthetic responses of two wheat cultivars. Using chlorophyll-fluorescence, the effects of heat stress at 37 °C and 45 °C for 8 hours on the seedlings of Karacadag and Firat wheat cultivars varying in sensitivity were examined. Genotypes with a higher Fv/Fm ratio also exhibited a higher yield, demonstrating that chlorophyll fluorescence is a significant criteria that may be used to screen for heat-tolerant genotypes.

2.3.7 Anthocyanin content

Anthocyanin pigments are flavonoid pigments that aid in biotic and abiotic stress resistance in plants. The pigmentation of anthocyanins in various plant areas correlates with their capacity to withstand environmental stress (Khlestkina, 2013). Lyu *et al.* (2020) observed that the anthocyanin content of plants cultivated in low nitrogen conditions decreased. According to their findings, nitrogen deprivation increases anthocyanin colouring in plants. Mbarki *et al.* (2018) discovered that a greater flavonol and anthocyanin accumulation in coloured wheat genotypes accelerated the development of adaptive responses to salt stress in wheat germplasm. Hilbert *et al.* (2003) demonstrated that nitrogen input reduces anthocyanin content, alters anthocyanin composition, and promotes anthocyanin breakdown in plants. Heimler *et al.* (2017) reviewed that nitrogen fertiliser decreased polyphenol content in nearly all plants.

2.4 Impact of heat stress on crop production and its constituents

Heat stress impacts every stage of wheat development, resulting in a decrease in yield. According to Rane *et al.* (2007), heat stress during the grain filling stage is responsible for the shortening of the grain development time and poor grain filling, which has a negative impact on the overall yield of the wheat crop. Other impacts of high temperature include decreased grain weight, shrunken grains, early senescence, decreased starch accumulation, changed starch-lipid composition in grains, impaired seed germination, and loss of vigour (Balla *et al.*, 2012). Numerous morphological, phenological, and physiological features have been linked to grain yield. Grain yield comprises phenological characteristics such as the number of tillers per plant, the number of spikelets per spike, the number of grains per spike, the weight of grains per spike, and the weight of one thousand grains (Przuli and Mladenov, 1999; Sunita *et al.*, 2017). Singh *et al.* (2014) showed a significant decrease in grain yield per plant, biological yield per plant, and grain yield per spike under conditions of late sowing. Similarly, Bala *et al.* (2014) showed substantial decreases in wheat grain production, number of grains per spike, plant height, grain filling time, and weight per 1000 kernels when exposed to high temperatures. Modarresi *et al.* (2010) found that high temperature stress in wheat considerably lowered all attributes, particularly grain yield (46.63 percent), 1000-grain weight (20.61 percent), and grain filling length (20.42 percent), whereas spikelets per spike (11.77%) was least impacted. Dhyani *et al.* (2013) found that yield drop was greatest (44.41%) for sensitive genotypes compared to tolerant genotypes under late-sowning conditions. Under heat stress, Hakim *et al.* (2012), Mohammadi *et al.* (2012b), and Sunita *et al.* (2017) reported a decline in wheat genotype yield and its characteristics. Grain shrank due to ultrastructural changes in the aleurone layer and endosperm cells induced by high temperature (Dias *et al.*, 2008). Pooja (2017) studied the effect of high temperature on twenty wheat genotypes' grain yield and biomass and found that WH1021 had the highest grain yield and biomass (0.534

kg/m2; 1.521 kg/m^2), followed by PBW 550 (0.487 kg/m^2; 1.340 kg/m^2) and HD 3059 (0.469 kg/m^2; 1.340 kg/m^2), while K0307 and WH711 had the lowest grain yield (0.169 kg/m^2; Shah *et al.* (2006) found that sowing date and variety had a substantial impact on emergence, number of productive and non productive tillers, spike length, grain yield, and biological yield. According to Kumar *et al.* (2014), the genotype HUW 234 seeded in the fourth week of November produced a greater yield. Results suggested that wheat production decreased when the daily mean post-anthesis temperature increased. High temperature at anthesis reduces grain number per spike and grain size, both of which have a significant impact on grain production (Yang *et al.*, 2002; Prasad *et al.*, 2008). Often, an increase in grain filling rate is not sufficient to compensate for a decrease in grain filling length when the temperature is elevated. Under heat stress, Pradhan *et al.* (2012) found that grain number per spike, individual grain weight, and grain production per plant decreased by 40, 56, and 70 %, respectively. Wheat genotypes NWL-10-14 (23.59 percent) and NWL-12-4 (19.60 percent) exhibited a significant reduction in spike length under LS conditions as compared to TS conditions, whereas KO-307 (13.33 percent), NWL-12-2 (14.85 percent), and NWL-12-13 (16.40 percent) exhibited a lesser reduction (Jaiswal *et al.*, 2018). All wheat cultivars saw a significant drop in yield and yield-related characteristics as heat stress intensified (Mian *et al.*, 2007; Rane *et al.*, 2007, Singh *et al.*, 2007b; Dwivedi *et al.*, 2017). According to Jalota *et al.* (2010), wheat grown early in November gave the maximum grain output.

2.5 Heat Susceptibility Index (HSI)

Heat Susceptibility Index (HSI) should be an essential criterion for breeding wheat genotypes that are tolerant to heat stress, as a lower HSI value indicates more tolerance. Based on HSI values, Bhardwaj *et al.* (2017) divided wheat genotypes into four groups: extremely heat resistant, tolerant, moderately tolerant, and sensitive. They determined that the parents Raj4083 and Raj4037, as well as the crosses Raj3765 Raj4037 and Raj3777 Raj4037, were desirable for the majority of the characters since their HSI values were less than 1. According to Kant *et al.* (2014), WH1069, WH730, UP2338, WH533, WH1021, WH595, HD2967, and RAJ3765 had HSI values less than 0.5, indicating that these cultivars are more resistant to high temperatures. Choudhary *et al.* (2015) observed that there were eighteen wheat genotypes, but only HD2888, Pusa gold, PBW343, Raj3765, F5-995, and K0583 were heat tolerant under both timely and late sowing circumstances. It demonstrates that considerable variances exist between genotypes and can be used in the production of high-yield wheat cultivars. Suresh *et al.* (2018) conducted an experiment to determine HSI in wheat and discovered that genotypes Raj3765, WH1080, and WH1142 had the lowest HSI; but in the triticale group, practically all genotypes had the lowest HSI values for various parameters, indicating great temperature tolerance of genotypes. Bhusal *et al.* (2017) screened 251 RILs for heat tolerance using HSI. Thay calculated HSI for every individual attribute and less than one was considered as tolerance genotype, while higher than one was considered susceptibility. The fact that HD2808 had less than one HSI for the majority of attributes while HUW510 had more than one indicates that HD2808 is heat-tolerant and HUW510 is heat-sensitive.

Shehrawat *et al.* (2020) screened 40 wheat accessions and four controls (WH711, WH542, WH1124, and HD3059) for heat tolerance based on various stress indices including heat susceptibility index (HSI), heat response index (HRI), heat tolerance index (HTI), mean productivity (MP), and geometric mean productivity (GMP) during rabi 2018-19. Under stress conditions, grain yield was shown to be favourably connected with HRI, HTI, MP, and GMP, and negatively correlated with HSI and TOL. The accessions DT 126, DT 46, DT 142, DT 102, and DT 124 were determined to be the most resistant to heat stress based on their heat susceptibility index and stress tolerance. It demonstrates that considerable variances exist among genotypes and can be used in the production of high yield wheat variants.

2.6 Nutrient analysis

With increases in temperatures due to global warming, plants are likely to experience increasingly frequent, hotter, and longer episodes of abrupt heat stress (e.g., heat waves) in the future, and this will negatively impact plant function. Based on the limited past studies, we know that heat stress can negatively affect plant nutrient relations (Heckathorn *et al.*, 2014). Consistent with the effects of moderate vs. severe heat stress on total plant N content and % N, moderate heat stress did not affect the rate of nutrient uptake per g of root, but severe heat stress did decrease the uptake rate of four of five nutrients examined (N, P, K, Fe vs. B). Heat stress also decreased N-uptake rate per g root in the warm-season C4 grass, *Andropogon gerardii*, as measured by both sequential harvesting and 15N labeling (Mainali *et al.,* 2014)

Giri *et al.* (2017) investigated the effects of heat stress on nutrient uptake and nutrient-uptake proteins, under heat stress in roots of tomato (*Solanum lycopersicum* L. cultivar Bigboy) results showed that in tomato, heat stress decreased total N content per plant [not shown, but = tissue N concentration (% N) × biomass (g), which both decreased, relative to control plants of the same age], by decreasing both plant growth (root growth more than shoot growth) and decreasing uptake rate of nutrients per g of root; similar negative effects of heat on total plant P, K, Fe, and B content were also observed.the uptake rate of P and K in detached corn root pieces during short-term incubations (thus reflecting heat effects on function, rather than concentration, of uptake proteins) increased up to 32 ◦C and 37 ◦C, with only small decreases at 37 ◦C and 42 ◦C, for K and P uptake, respectively (Bravo and Uribe 2018). Chopra (2018) found that optimal activity of nitrate reductase in leaves of eight different crop species occurred at >45 ◦C during short-term incubations. In contrast, Hungria and Kaschuk (2014) observed that chronic heat stress (18–38 days at 28 ◦C vs. 34 ◦C or 39 ◦C daytime) decreased the activities of nitrogenase, nitrate reductase, GS, and (especially)

GOGAT, in leaves or nodules of the legume, *Phaseolus vulgaris*; heat also decreased the transport of N in xylem. Similarly, chronic heating (10–20 days at 20 ◦C vs. 35 ◦C daytime) decreased GS and GOGAT activities in fescue leaves (Festuca arundinacea) (Cui *et al.*, 2016). These limited results suggest that, unless temperatures reach extremely-high levels, heat stress likely decreases the activities of N metabolism proteins by decreasing their concentration in plant tissues, rather than inhibiting the function of individual N-metabolism proteins.

CHAPTER-III

MATERIALS AND METHODS

The present study entitled **“Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions''** was conducted during *rabi* season of 2021-22. The research was conducted with the aims:-

1. To evaluate the photosynthetic efficiency and nutrient uptake in wheat genotypes
2. To find correlation between photosynthetic efficiency and nutrient uptake with high temperature tolerance

3. Details of experiment

3.1 Location of experimental site

The experiment was conducted in eathern pots under screen house condition, Department of Botany and Plant physiology, CCS Haryana Agricultural University, Hisar, located at latitude of 29º 10' N, longitude of 75º 46' E and at an altitude of 215.2 meters above mean sea.

3.2 Chemicals

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

3.3 Raising of the crop and experimental material

Seeds of six wheat genotype (WH147, WH711, WH1105, WH1184, HD2967, and WH1021) were obtained from Wheat and Barley Section, Department of Genetics and Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar (Haryana).

Table 3.1: Chemical composition of the Hoagland nutrient solution (Arnon and Hoagland, 1950):

Major salt	Chemical	Concentration
Stock solution 1	$Ca\ (NO_3)_2$	364.0 gL^{-1}
Stock solution 2	KNO_3	221.3 gL^{-1}
Stock solution 3	$MgSO_4$	217.6 gL^{-1}
Stock solution 4	KH_2PO_4	62.1 gL^{-1}
Micronutrients		
Stock solution 5	$ZnSO_4$	0.097 g
	H_3BO_3	1.269 g
	Na_2MoPO_4	0.400 g
	$CuSO_4.5H_2O$	0.035 g
	$MnSO_4$	0.609 g
	Volume with water	1 L
Iron Source		
Stock solution 6	Tartaric acid	0.6 g L^{-125}
	Ferric citrate	0.6 gL^{-125}

*All the stocks were made separately

*Shelf life 4-6 months

*For dissolving [Ca(NO3) 2] and (KNO3) heating was required

*For 25 l nutrient solution take 62.5 ml of each stock I-V.

Plants were raised in eathern pots (20 x 16 cm) with 5 kg dune sand.These pots were placed in screen house under natural conditions and the soil was saturated with tap water. Seeds were sterilized with alcohol, washed 3-4 times with distilled water and dried on filter paper. Six seeds were sown in each pot at uniform depth and distance.Thinning was done one week after germination to leave three plants of comparable growth in each pot. The plants were supplied with nutrient solution (Hoagland and Arnon, 1950) at regular intervals.

3.4 Environments

The seeds of all six wheat genotypes were grown at three dates of sowing i.e., 17th November, 2021, 15th December, 2021 and 8th January, 2022 termed as (TS- Timely sown), (LS- Late sown) and (VLS- Very Late sown) condition respectively.

3.5 Statistical analysis

Mean values of the observation recorded from each replication were utilized for statistical analysis. The data was analyzed by analysis of variance for the complete randomized block design using OPSTAT software available at the Computer Centre, Department of Mathematics and Statistics, CCS Haryana Agricultural University, Hisar and CD at 5 % was calculated.

3.6 Replications: For each parameter three replications were sampled at a time.

3.7 Observations recorded

All analytical work was done at the stress physiology laboratory of Department of Botany and Plant physiology. Observations were recorded on three randomly selected plants per genotype per replication.

3.7.1 Physiological characters

Flag leaf per selected plant was randomly chosen and was used to measure physiological traits at different grain filling stage starting from day of anthesis at interval of seven days till maturity (at 7 and 14 days after anthesis). The observations for all the parameters were recorded in triplicate and mean of the three readings.

3.7.2 Observations on plant

A) Canopy temperature (^{0}C): Canopy temperature (CT) measurements were made using hand held infrared thermometer (IRT), model AG-42, Tele temp crop Fullerton. Three measurements were taken per genotype at approximately 0.5 m from the edge of the plot and approximately 0.5 m above the canopy with an approximately 30-60° from the horizontal. The canopy temperature (CT) was measured between 12:00 to 14:00 hours on cloudless, bright days when there was no wind and from sun side to avoid shadowing effect. Readings were taken at 45, 75, and 105 DAS in all wheat genotypes under TS, LS and VLS conditions.

B) Fresh weight-root, stem and leaves (g plant^{-1}): Fresh weight of root, stem and leaves from each genotype were measured immediately after taken from pots on weighing machine at 45,75 and 105 DAS under TS, LS and VLS conditions.

C) Dry weight-root, stem and leaves (g plant^{-1}): Dry weight of root, stem and leaves of each genotype were measured after taken from pots on weighing machine and after that samples were dried in an oven at 80^{0}C for 48 hr at 45,75 and 105 DAS under TS, LS and VLS conditions.

Observations on Flag leaf

A) Gas exchange attributes

Photosynthetic rate (µmol m^{-2}s^{-1}), transpiration rate (mol m^{-2}s^{-1}) and stomatal conductance (mmol m^{-2}s^{-1}) of fully expended leaf was measured by infrared gas analyzer (IRGA LCi-SD, ADC Biosciences). The leaf was enclosed in the assimilation chamber and position was shifted such that maximum PAR was obtained then photosynthetic rate (A), transpiration rate (E) and stomatal conductance (gs) was monitored while CO_2 concentration changed over a definite time interval. The system automatically calculated the A, E and gs on the basis of preloaded flow rate and leaf area. Measurements were taken only in the morning time i.e. at 10:00 AM to 11:00 AM. When relative humidity, temperature, photosynthetic photon flux density and amp; CO_2 concentration ranged from 50–60 %, 25–35°C, 1200 µmole (photon) m^{-1}s^{-1} and amp; 350–360 µmole^{-1}, respectively.

B) Chlorophyll Content Index (CCI)

The Chlorophyll content was measured at 7 and 14 days after anthesis by chlorophyll meter (Model No. Minolta SPAD-502 Plus) which measure the greenness or 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: red LED) absorbed by the tissue sample. A second peak (peak wavelength: approximately 940 nm: infrared LED) was emitted simultaneously with red LED to compensate the thickness of leaf.

C) Anthocyanin content

The anthocyanin content was measured using Force A Dualex optical leaf clipper meter (FORCE-A, Orsay, France) where clean, dry, green flag leaf of three plants of all the six genotype under all three sowing environment conditions were selected and kept between the sensor avoiding the central rib of the leaf. Anthocyanin content is measured in relative absorbance unit by comparing the near infrared chlorophyll fluorescence with a sampling light specific to anthocyanin (green).

D) Chlorophyll fluorescence (Fv/Fm)

The chlorophyll fluorescence was measured by using chlorophyll fluorometer (0S-30p Opti- Sciences U.S.A). 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 fluorescence signals were detected as FO, FM and FV/FM. The data was analyzed, which provides parameters indicating the efficiency of photosystem II. Data was recorded between 10:00 A.M. to 12:00 noon.

3.7.3 Yield and its component

A) Number of days to heading

The date on which the 50% spikes emerged was recorded and the numbers of days were calculated from the date of sowing.

B) Number of days to anthesis

The date on which the 50% spikes showed anthers was recorded and the numbers of days were calculated from the date of sowing.

C) Number of days to maturity

The date on which 50% ear heads lost green color was recorded and numbers of days were calculated from the date of sowing

D) Plant height (cm)

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

E) Number of spikelets per spike

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

F) Spike length (cm)

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

G) Biomass (g/m^2)

Plants were cut from the base of stem at maturity and weight was taken by using spring balance in gram and average was taken.

H) Number of grains/ spikes

The threshed grains from spikes were counted to obtain grain number/spike.

I) Grain weight/ spike (g)

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

J) Grain yield (g/plant)

Grain yield from each plant was recorded in g/plant.

K) 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 record.

3.7.4 Heat Susceptibility Index (HSI)

Heat susceptibility index of individual genotype was calculated by the method suggested by Fisher and Maurer (1978) with the following formula:

$$HSI = \left(1 - \frac{Y_s}{Y_p}\right) / D$$

Where,

D : 1- X/XP

$\mathbf{Y_p}$: Potential grain yield of individual genotype

$\mathbf{Y_s}$: Yield under heat stress for individual genotype

$\mathbf{X_s}$: mean grain yields of all genotypes under stress condition

$\mathbf{X_p}$: represents mean grain yields of all genotypes under non-stress condition

3.8 Nitrogen, Phosphorus and Potassium content (Root, Stem and Leaves):

The content of nitrogen and phosphorus were estimated in the root, stem and leaves of plant after harvest of wheat.

Digestion of plant material

Oven dried root, stem and leaves samples weighed 0.1 and 0.2 g, respectively were taken in 50 ml separate conical flasks and 5 ml di-acid mixture (H_2SO_4 : $HClO_4$ in 9:1 ratio) was added to each flask. Digestion on a hot plate was carried out until a clear colorless solution results or till white fumes cease to come out. Cool it and the total volume of aliquot was made to 50 ml by adding distill water.

3.8.1 Nitrogen Content

The nitrogen content was determined by using the method as Lindner (1994).

Reagents

1. Sodium silicate (10 %) solution: 10 g of sodium silicate was dissolved in 100 ml distilled water and filtered.
2. Sodium hydroxide (10 %) solution: 10 g sodium hydroxide was dissolved in 100 ml distilled water and filtered.
3. Nessler's reagent: The 100 g of mercuric iodide (HgI) and 70 g potassium iodide (KI) were dissolved in 400 ml of water. A 100 g of NaOH was dissolved in another 400 ml of water. The two solutions were mixed and the volume was made one litre with distilled water.

Procedure

The aliquot of 0.2 ml was taken into 50 ml volumetric flask. To this aliquot, 0.1 ml of sodium silicate and 0.1 ml of 10 % NaOH were added. Neck washing was done after the addition of every reagent and the contents were mixed thoroughly. Then 0.1 ml Nessler's reagent was added dropwise while shaking. The solution was allowed to stand for 30 minutes at room temperature and final volume was made to 25 ml. Read the intensity of colour on spectrophotometer by using blue filter at 440 nm wavelength. A standard curve was prepared from graded concentration of NH_4Cl. The nitrogen content was calculated using the standard curves.

3.8.2 Phosphorus Content

The phosphorus content was determined by vando-molybdophosphoric acid yellow colour method as described by Koenig and Johnson (1942).

Reagents

1. Vandate-molybdate reagent: The solution 'A' was prepared by dissolving 25 g of ammonium molybdate in about 400 ml of warm water and another solution 'B' was prepared separately by dissolving 1.25 g of ammonium metavandate in about 300 ml of warm water and then cooled at room temperature and 250 ml of concentrated HNO_3 was added to this solution and cooled again at room temperature. Thereafter, the solution 'A' was added to solution 'B' with continuous stirring and diluted to one litre with distilled water.
2. 6N HCl solution: The 513 ml of concentrated HCl was diluted to one litre.
3. 2, 4 Dinitrophenol indicator 2.5 %: The 2.5 g of 2, 4 dinitrophenol was dissolved in 100 ml of 95 % ethanol.
4. Ammonia solution

Procedure

Five milliliters of aliquot was taken into 50 ml volumetric flask. Then, 2-3 drops of 2, 4 dinitrophenol indicator were added to this aliquot. To this solution, ammonia solution was added until the yellow colour appeared and 6 N HCl was also added until it became colourless. Then, 5 ml of vandamolybedate solution was added and diluted to 25 ml with distilled water. This solution was mixed thoroughly and the optical density was measured at 440 nm against the reagent blank on UV-Visible spectrophotometer. The phosphorus content was calculated by using the standard curve.

3.3.3 Potassium Content

The potassium contents of the roots, stems and leaves were determined from the oven-dried (85°C) and grounded material by using Flame Photometer.

Reagents required

- Standard solution (1000ppm).
- Neutral ammonium acetate solution (1N) - Dilute 570 ml of glacial acetic acid (99.5%) with deionised water to a volume of approximately 5 litres. Then add 690ml of concentrated ammonium hydroxide (NH4OH) and add deionised water to obtain a volume of about 9.9 litres. Adjusted the pH of the solution to 7 and diluted the solution to a volume of 10 litres with deionised water.
- Deionised water

Digestion procedure:

Fifty mg of dried and well-ground plant material was digested in three ml of 9:1 mixture of concentrated H_2SO_4 (91-100 %) and $HClO_4$ (50 %) by heating gently on a hot plate till the solution became colourless. The solution was cooled and the total volume was made up to 25 ml with distilled water. Potassium content were determined by using Flame Photometer (Elico, India) and expressed in ppm values. Before the determination of potassium content of tissue digested, it was calibrated for operation over-concentration of 0-100 of sodium and potassium, using the graded concentration of KCl. From ppm values, K contents were converted to mg g^{-1} DW basis. Potassium content of the resulting solution was then determined using Flame Photometer

Meteorological data

The data of temperature and rainfall during the season was obtained from the observatory, Department of Meteorological Science, CCS HAU, Hisar (Table 3.2 and 3.3). The data indicated that there was no rainfall in the month of March (2022).Average maximum temperature (40.24ºC) was observed during the month of April, 2022 whereas average minimum temperature (6.34°C) was observed during the month of December (2021). Experiments faced short episode of higher temperature (>25°C) during the month of March and April, 2022. These periods coincide for taking physiological observation under timely, late and very late sown conditions.

Table 3.2 Average Temperature and Rainfall during Wheat crop season 2021-2022

Sr. No.	Month	Temperature (°C)		Total Rainfall (mm)
		Maximum	Minimum	
1	November	27.9	9.9	0.01
2	December	21.2	6.3	0.03
3	January	16.4	7.1	2.06
4	February	23.1	8.1	0.25
5	March	31.8	13.8	0.00
6	April	40.2	19.0	0.05

Table 3.3 Relative Humidity and Sunshine during Wheat crop season 2021-22

Sr. No.	Month	Relative Humidity (%)		Bright Sunshine Hours (hrs.)
		M (%)	E (%)	
1	November	89.4	34.2	5.52
2	December	94.9	50.1	4.99
3	January	97.5	70.0	2.82
4	February	93.8	51.2	7.15
5	March	87.2	35.3	7.79
6	April	68.9	33.50	8.52

CHAPTER-IV

EXPERIMENTAL RESULTS

In the present investigation, six wheat genotypes were evaluated for thermo-tolerance under timely, late conditions and very late sown conditions. The crop was sown in three environments viz. TS, LS and VLS condition in *Rabi* season 2021-2022 at screen house of the Department of Botany and Plant Physiology, College of Basic Sciences and Humanities, CCS HAU, Hisar in completely Randomized Design. All observations were recorded in three replications under all conditions.The results achieved are summarized as under:

4.1 Physiological Traits: -

4.1.1 Observations on Plant

Canopy temperature (°C) and fresh and dry weight of root, stem and leaves were observed at 45, 75 and 105 DAS in all wheat genotypes under timely, late and very late sown conditions.

4.1.1.1 Canopy temperature (°C)

Canopy temperature (CT) (°C) of wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.1. At 45 DAS, minimum CT was observed in wheat genotype WH711 (16.2) followed by WH147 (16.7) and WH1021 (16.9) under TS while in WH711 (16.2) followed by WH1021 (17.3) and WH1105 (17.5) under LS condition. In very late sown conditions the minimum CT was observed in WH1105 (18.1) followed by HD2967 (18.2) and WH1184 (20.5). However, maximum CT was observed in WH1105 (17.3) followed by WH1184 (17.2) and HD2967 (17.1) under TS condition while in LS condition, WH147 (20.2) followed by WH1184 (20.1) and HD2967 (18.4) showed maximum CT. In VLS conditions the maximum CT was observed in WH1021 (21.5) followed by WH711 (21.0).

At 75 DAS, minimum CT was observed in wheat genotype WH147 and WH711 (18.7) followed by HD2967 (19.1) under TS conditions while WH1105 (18.7) followed by HD2967 (19.3) and WH711 (20.0) under LS conditions. Under VLS conditions minimum CT was observed in HD2967 (29.6) followed by WH1184 (29.9). However maximum CT was observed in WH1021 (19.7) followed by WH1105 (19.3) and WH1184 (19.2) under TS whereas under LS condition WH147 (21.4) followed by WH1184 (21.3) and WH1021 (21.0) while under VLS WH1021 and WH1105 showed maximum CT.

At 105 DAS, lowest CT was observed in wheat genotype WH1105 (18.5) followed by WH1184 (20.4) and WH1021 (21.3) under TS while in WH1184 (33.9) followed by WH147 (34.2) and WH711 (34.3) under LS whereas in VLS, WH1105 (35.0) followed by HD2967 and WH1184 (35.4). However maximun CT was observed in HD2967 (22.4) followed by WH711 (22.3) under TS and in HD2967 (35.2) followed by WH1021(35.0) and WH1105(34.5) under LS and in WH711(36.5) followed by WH1021(36.3) and WH147 (36.6) under VLS.

Table 4.1: Canopy temperature (°C) of wheat genotypes at 45, 75 and 105 DAS under timely, late and very late sown conditions

Wheat Genotype	**Canopy Temperature (°C)**											
	45DAS				**75 DAS**				**105 DAS**			
	TS	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**
WH147	16.7	20.2	20.9	**19.3**	18.7	21.4	30.9	**23.7**	21.5	34.2	35.6	**30.4**
WH711	16.2	16.2	21.0	**17.8**	18.7	20.0	29.4	**22.7**	22.3	34.3	36.5	**31.0**
WH1105	17.3	17.5	18.2	**17.7**	19.3	18.7	31.3	**23.1**	18.5	34.5	35.0	**29.3**
WH1184	17.2	20.1	20.5	**19.3**	19.2	21.3	29.9	**23.5**	20.4	33.9	35.4	**29.9**
HD2967	17.1	18.4	18.6	**18.0**	19.1	19.3	29.6	**22.7**	22.4	35.2	35.4	**31.0**
WH1021	16.9	17.3	21.5	**18.6**	19.7	21.0	31.3	**24.0**	21.3	35.0	36.3	**30.9**
Mean	**16.9**	**18.3**	**20.1**		**19.1**	**20.3**	**30.4**		**21.1**	**34.5**	**35.7**	
C.D at 5 %	G =0.66, E =0.93, G x E = 1.62				G =1.06, E =NS, G x E = NS				G =0.40, E =NS, G x E = 0.99			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.1.1.2 Fresh weight

4.1.1.2.1 Leaves Fresh weight

Fresh weight (g) of leaves in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.2. At 45 DAS, maximum FW was observed in wheat genotype WH1021 (0.461) followed by HD2967 (0.447) under TS while in HD2967 (0.418) followed by WH1021 (0.402) under LS condition and in HD2967 (0.323) followed by WH1021 (0.311) VLS condition. At 75 DAS, wheat genotype, WH1021 showed maximum FW of 0.578, 0.529, and 0.432 g/plant under TS, LS and VLS conditions. However at 105 DAS, maximum FW was observed in wheat genotype HD2967 (0.658) followed by followed by WH1021 (0.627) under TS, in HD2967 (0.616) followed by WH1021 (0.576) under LS and in HD2967 (0.587 g) followed by WH1021 (0.542 g) under VLS conditions.

At 45 DAS, minimum average leaves FW was observed in WH147, 0.291, 0.369, and 0.461 respectively under TS, LS and VLS. At 75 DAS, minimum FW was observed in WH147 (0.471) followed by WH711 (0.508) under TS condition and a similar trend for FW was observed under LS, WH147 (0.412), followed WH711 (0.448) and VLS conditions, WH147 (0.305) followed by WH711 (0.319). At 105 DAS wheat genotype WH147 showed minimum FW as compared to other genotypes under TS, LS and VLS conditions.

Table 4.2: Fresh weight (FW) of leaves (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions.

Wheat Genotype	Fresh weight (FW) of leaves (g) /plant											
	45DAS				75 DAS				105 DAS			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	0.376	0.312	0.186	**0.291**	0.471	0.412	0.305	**0.396**	0.532	0.442	0.409	**0.461**
WH711	0.378	0.303	0.206	**0.296**	0.508	0.448	0.319	**0.425**	0.547	0.488	0.436	**0.490**
WH1105	0.427	0.358	0.284	**0.356**	0.525	0.465	0.349	**0.446**	0.587	0.539	0.495	**0.540**
WH1184	0.440	0.380	0.297	**0.372**	0.541	0.481	0.389	**0.470**	0.610	0.550	0.513	**0.558**
HD2967	0.447	0.418	0.323	**0.396**	0.562	0.506	0.407	**0.492**	0.658	0.616	0.587	**0.620**
WH1021	0.461	0.402	0.311	**0.391**	0.578	0.529	0.432	**0.513**	0.627	0.576	0.542	**0.582**
Mean	**0.414**	**0.362**	**0.268**		**0.531**	**0.474**	**0.367**		0.594	0.535	0.497	
C.D at 5 %	G =0.01, E =0.01, G x E = 0.01				G =0.01, E =0.01, G x E =0.02				G =0.01, E =0.02, G x E = Ns			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.1.1.2.2 Stem Fresh weight (g/plant)

Fresh weight (FW) of stem in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.3. Reduction in FW was observed in all genotype at all growth stages under LS and VLS as compared to TS conditions. At 45 DAS, maximum FW was observed in wheat genotype WH1021 (0.54) followed by WH1184 (0.499) under TS, in WH1021 (0.442) followed by WH1184 (0.395) under LS condition and in WH1021 (0.379) followed by HD2967 (0.358) under VLS conditions. At 75 DAS, wheat genotype HD2967 showed maximum stem FW of 0.954, 0.876, and 0.723 g/plant followed by wheat genotype WH1021 0.869, 0.791 and 0.651 g/plant repectively under TS, LS and VLS conditions. At 105 DAS, maximum FW was observed in wheat genotype HD2967 (1.92g) followed by followed by WH1021 (1.837), and WH 1184 (1.70) under TS conditions. HD2967 genotype further maintained maximum FW under LS (1.375) and VLS (1.021) conditions.

However, 45 DAS minimum fresh weight was observed in WH147 (0.399) followed by HD2967 (0.408) under TS condition, in WH147 (0.253) followed by WH711 (0.299) under LS and in WH147 (0.199) followed by WH711 (0.22) VLS conditions.

At 75 DAS minimum FW was observed in WH711 (0.745) followed by WH147 (0.779) under TS while in LS condition, WH711 (0.665) followed by WH147 (0.679) showed minimum fresh weight. In VLS conditions the minimum fresh weight was observed in WH147 (0.478) followed by WH711 (0.525g). At 105 DAS wheat genotype WH147 recored for minimum FW of 1.456, 0.888 and 0.722g repectively under TS, LS and VLS conditions.

Table 4.3: Fresh weight (FW) of stem (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions.

Wheat Genotype	**Fresh weight (FW) of stem (g) /plant**											
	45DAS				**75 DAS**				**105 DAS**			
	TS	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**
WH147	0.399	0.253	0.199	**0.284**	0.779	0.679	0.478	**0.645**	1.456	0.888	0.722	**1.022**
WH711	0.432	0.299	0.225	**0.319**	0.745	0.665	0.525	**0.645**	1.569	0.925	0.745	**1.080**
WH1105	0.489	0.347	0.312	**0.383**	0.798	0.721	0.582	**0.700**	1.679	1.086	0.799	**1.188**
WH1184	0.499	0.395	0.356	**0.417**	0.818	0.739	0.602	**0.720**	1.701	1.123	0.873	**1.232**
HD2967	0.408	0.372	0.358	**0.379**	0.954	0.876	0.723	**0.851**	1.920	1.375	1.021	**1.439**
WH1021	0.537	0.442	0.379	**0.453**	0.869	0.791	0.651	**0.770**	1.837	1.294	0.869	**1.333**
Mean	0.461	0.351	0.305		0.827	0.745	0.594		1.694	1.115	0.838	
C.D at 5 %	G =0.01, E =0.01, G x E = 0.02				G =0.01, E =0.02, G x E =0.03				G =0.02, E =0.03, G x E = 0.05			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.1.1.2.3 Root Fresh weight (g)/plant

Fresh weight (FW) of roots (g)/plant in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are dipicted in Table 4.4. A reduction in FW was observed at all stages in all wheat genotypes. At 45 DAS highest FW was observed in wheat genotype HD2967 (0.341) followed by WH1021 (0.296) under TS while in HD2967 (0.231) followed by WH1021 (0.199) under LS condition. In very late sown conditions the maximum FW was observed in HD2967 (0.205) followed by WH1021 (0.176). However, minimum FW was observed in WH147 (0.204) followed by WH711 (0.213) under TS condition while wheat genotype WH147 (0.124) followed by WH711 (0.133) under LS and in WH147 (0.103) followed by WH711 (0.113) under VLS conditions showed minimum FW.

At 75 DAS, maximum FW was observed in wheat genotype HD2967 (0.444) followed by WH1184 (0.418) under TS while in HD2967 (0.371) followed by WH1021 (0.34) under LS and in HD2967 (0.319) followed by WH1021 (0.285) under VLS condition. However, minimum fresh weight was observed in WH147 followed by WH711 under TS, LS and VLS conditions. Wheat genotype WH147 showed root FW of 0.309, 0.234 and 0.201 g/plant under TS, LS and VLS respectively.

At 105 DAS, wheat genotype HD2967 (0.655) followed by WH1021 (0.637) showed maximum FW under TS, and the similar trend was maintained under LS and VLS conditions. However, minimum FW was recorded in WH147 followed by WH711 under TS condition, LS and VLS (Table 4.4).

Table 4.4: Fresh weight (FW) of roots (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions.

Wheat Genotype	Fresh weight of root (g) /plant											
	45DAS				75 DAS				105 DAS			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	0.204	0.124	0.103	**0.144**	0.309	0.234	0.201	**0.248**	0.497	0.412	0.319	**0.409**
WH711	0.213	0.133	0.113	**0.153**	0.324	0.251	0.206	**0.260**	0.522	0.435	0.344	**0.434**
WH1105	0.256	0.156	0.126	**0.179**	0.380	0.286	0.233	**0.300**	0.589	0.523	0.410	**0.507**
WH1184	0.272	0.182	0.152	**0.202**	0.418	0.327	0.252	**0.332**	0.612	0.552	0.438	**0.534**
HD2967	0.341	0.278	0.205	**0.275**	0.444	0.371	0.319	**0.378**	0.655	0.596	0.497	**0.583**
WH1021	0.296	0.206	0.176	**0.226**	0.409	0.340	0.285	**0.345**	0.637	0.579	0.469	**0.562**
Mean	**0.264**	**0.180**	**0.146**		**0.381**	**0.302**	**0.249**		**0.585**	**0.516**	**0.413**	
C.D at 5 %	G =0.003, E =0.005, G x E = 0.008				G =0.01, E =0.01, G x E =0.01				G =0.01, E =0.01, G x E = 0.03			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.1.1.3 Dry weight (g/plant)

4.1.1.3.1 Leaves Dry weight

Dry weight (g) of leaves in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.5. At 45 DAS, maximum dry weight was observed in wheat genotype HD2967 (0.196) followed by WH1021 (0.188) under TS while in HD2967 (0.182) followed by WH1021 (0.164) under LS condition. In very late sown conditions the maximum dry weight was observed in HD2967 (0.163) followed by WH1021 (0.149). However, minimum dry weight was observed in WH147 (0.148) followed by WH711 (0.168) under TS condition while in LS condition, WH147 (0.113) followed by WH711 (0.126) showed minimum dry weight. In very late sown conditions the minimum dry weight was observed in WH147 (0.090) followed by WH711 (0.099).

At 75 DAS, maximum dry weight was observed in wheat genotype HD2967 (0.259) followed by WH1021 (0.249) under TS while in HD2967 (0.217) followed by WH1021 (0.201) under LS condition. In very late sown conditions the maximum dry weight was observed in HD2967 (0.188) followed by WH1021 (0.178). However, minimum dry weight was observed in WH147 (0.207) followed by WH711 (0.211) under TS condition while in LS condition, WH147 (0.143) followed by WH711 (0.151) showed minimum dry weight. In very late sown conditions the minimum dry weight was observed in WH147 (0.122) followed by WH711 (0.137).

Table 4.5: Dry weight (DW) of leaves (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions.

Wheat Genotype	Dry weight of leaves (g) /plant											
	45DAS				75 DAS				105 DAS			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	0.148	0.113	0.090	**0.117**	0.207	0.143	0.122	**0.157**	0.233	0.146	0.118	**0.166**
WH711	0.168	0.126	0.099	**0.131**	0.211	0.151	0.137	**0.166**	0.243	0.153	0.147	**0.181**
WH1105	0.174	0.136	0.128	**0.146**	0.227	0.179	0.151	**0.186**	0.279	0.182	0.169	**0.210**
WH1184	0.183	0.155	0.140	**0.159**	0.233	0.182	0.163	**0.193**	0.297	0.212	0.193	**0.234**
HD2967	0.196	0.182	0.163	**0.180**	0.259	0.217	0.188	**0.221**	0.328	0.238	0.226	**0.264**
WH1021	0.188	0.164	0.149	**0.167**	0.249	0.201	0.178	**0.209**	0.312	0.223	0.208	**0.248**
Mean	**0.176**	**0.146**	**0.128**		**0.231**	**0.179**	**0.157**		**0.282**	**0.192**	**0.177**	
C.D at 5 %	G =0.003, E =0.005, G x E = 0.008				G =0.003, E =0.004, G x E =0.007				G =0.004, E =0.005, G x E = 0.009			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

At 105 DAS, maximum dry weight was observed in wheat genotype HD2967 (0.328) followed by WH1021 (0.312) under TS while in HD2967 (0.238) followed by WH1021 (0.223) under LS condition. In very late sown conditions the maximum dry weight was observed in HD2967 (0.226) followed by WH1021 (0.208). However, minimum dry weight was observed in WH147 (0.233) followed by WH711 (0.243) under TS condition while in LS condition, WH147 (0.146) followed by WH711 (0.153) showed minimum dry weight. In very late sown conditions the minimum dry weight was observed in WH147 (0.118) followed by WH711 (0.147).

4.1.1.3.2 Stem Dry weight (g/plant)

Dry weight (g) of stem in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.6. At 45 DAS, maximum DW was observed in wheat genotype HD2967 was 0.202, 0.175, and 0.148 under TS, LS and VLS respectively followed by genotype WH1021 with 0.199, 0.170 and 0.141g. However, minimum dry weight was observed in WH147 (0.105) followed by WH711 (0.129), WH1105 (0.163) under TS condition while in LS condition, WH147 (0.071) followed by WH711 (0.101), WH1105 (0.136). Similar results were obsereved for minimum stem dry weight at VLS conditions.

At 75 DAS, maximum DW was recorded in wheat genotype HD2967 followed by WH1021, WH 1105, WH 1184, WH711 and WH147 under all three environments viz TS, LS and VLS conditions (Table 4.6). At 105 DAS, maximum dry weight was again observed in wheat genotype HD2967 (0.716) followed by WH1021 (0.693) under TS while in HD2967 (0.563) followed by WH1021 (0.512) under LS condition. In very late sown conditions the maximum dry weight was observed in HD2967 (0.445) followed by WH1021 (0.415). However, minimum dry weight was observed in WH147 (0.489) followed by WH711 (0.567) under TS condition while in LS condition, WH147 (0.328) followed by WH711 (0.412) showed minimum dry weight. In very late sown conditions the minimum dry weight was observed in WH147 (0.228) followed by WH711 (0.269).

Table 4.6: Dry weight (DW) of stem (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions

Wheat Genotype	Dry weight of stem (g) /plant											
	45DAS				75 DAS				105 DAS			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	0.105	0.071	0.060	**0.079**	0.278	0.219	0.102	**0.200**	0.489	0.328	0.228	**0.348**
WH711	0.129	0.101	0.076	**0.102**	0.300	0.245	0.122	**0.222**	0.567	0.412	0.269	**0.416**
WH1105	0.163	0.136	0.112	**0.137**	0.327	0.267	0.187	**0.260**	0.582	0.417	0.342	**0.447**
WH1184	0.189	0.156	0.134	**0.160**	0.346	0.290	0.213	**0.283**	0.645	0.430	0.389	**0.488**
HD2967	0.202	0.175	0.148	**0.175**	0.437	0.374	0.297	**0.369**	0.716	0.563	0.445	**0.575**
WH1021	0.199	0.170	0.141	**0.170**	0.375	0.315	0.247	**0.312**	0.693	0.512	0.417	**0.541**
Mean	**0.165**	**0.135**	**0.112**		**0.344**	**0.285**	**0.195**		**0.615**	**0.444**	**0.348**	
C.D at 5 %	G =0.003, E =0.004, G x E = 0.007				G =0.004, E =0.006, G x E =0.01				G =0.009, E =0.012, G x E = 0.021			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.1.1.3.3 Root Dry weight (g/plant)

Dry weight (g) of root in wheat genotypes at 45, 75 and 105 DAS under TS, LS and VLS conditions are shown in Table 4.7. Wheat genotype HD 2967 showed the maximum mean DW of 0.111, 0.151 and 0.202 g/plant at 45, 75 and 105 DAS respectively. AT 105 DAS wheat genotype showed minimum reduction percentage in root DW as compared to TS conditions was WH1021 (10.2%) followed by HD2967 (11.4%) under LS, and HD2967 (22.8%) followed by WH 1021 (23.7) and WH1184 (23.1 %) under VLS conditions. This trend was similar as reported at 45 and 75 DAS after sowing.

At 75 DAS, maximum dry weight was observed in wheat genotype HD2967 (0.174) followed by WH1021 (0.169) under TS while in HD2967 (0.154) followed by WH1021 (0.139) under LS condition. In very late sown conditions the maximum dry weight was observed in HD2967 (0.125) followed by WH1021 (0.119). At 105 DAS, maximum dry weight was observed in wheat genotype HD2967 (0.228) followed by WH1021 (0.208) under TS while in HD2967 (0.202) followed by WH1021 (0.182) under LS condition. In very late sown conditions the maximum dry weight was observed maintained in HD2967 (0.176) followed by WH1021 (0.157). However, minimum DW of root observed in WH147 with 0.091, 0.073, and 0.047g/plant DW under TS, LS and VLS conditions at 45 DAS. A similar trend was observed in minimum root DW at 75 and 105 DAS.

Table 4.7: Dry weight (DW) of roots (g) /plant in wheat genotype at 45, 75 and 105 DAS under timely, late and very late sown conditions.

Wheat Genotype	**Dry weight of root (g) /plant**											
	45DAS				**75 DAS**				**105 DAS**			
	TS	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**
WH147	0.091	0.073	0.047	**0.070**	0.131	0.098	0.084	**0.104**	0.159	0.127	0.109	**0.132**
WH711	0.097	0.075	0.059	**0.077**	0.129	0.094	0.082	**0.102**	0.162	0.135	0.119	**0.139**
WH1105	0.102	0.082	0.067	**0.084**	0.157	0.117	0.107	**0.127**	0.174	0.149	0.130	**0.151**
WH1184	0.112	0.093	0.074	**0.093**	0.162	0.122	0.114	**0.133**	0.186	0.161	0.143	**0.163**
HD2967	0.128	0.113	0.092	**0.111**	0.174	0.154	0.125	**0.151**	0.228	0.202	0.176	**0.202**
WH1021	0.119	0.102	0.079	**0.100**	0.169	0.139	0.119	**0.142**	0.206	0.185	0.157	**0.183**
Mean	**0.108**	**0.090**	**0.070**		**0.152**	**0.123**	**0.107**		**0.186**	**0.160**	**0.139**	
C.D at 5 %	G =0.002, E =0.003, G x E = 0.004				G =0.002, E =0.002, G x E =0.004				G =0.002, E =0.003, G x E = 0.006			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.2.2.4 Nitrogen (N) Content in Root, Stem and Leaves

Table 4.8 demonstrates the nitrogen content of six wheat genotypes in roots, stem and leaves under TS, LS and VLS condition. In Roots, maximum nitrogen content was observed in wheat genotype HD2967 (1.60) followed by WH 1105 (1.35), WH1021 (1.32), WH 711 (1.26), WH 147 (1.22) and WH 1184 (1.20) under TS while in HD2967 (1.39) followed by WH1021 (1.15), WH1105 (1.12), WH 711, WH 147 and WH 1184 (1.0) under LS condition. In very late sown conditions the maximum nitrogen content was observed in HD2967 (1.12) followed by WH1021 (0.92), WH147 (0.81), WH 1184 (0.72), WH 1105 (0.68), and WH 711 (0.61).

In Stem, maximum nitrogen content was observed in wheat genotype HD2967 (11.8) followed by WH1105 (10.40) under TS while in HD2967 (10.4) followed by WH1105 (9.0) under LS condition. In very late sown conditions the maximum nitrogen content was observed in HD2967 (7.7) followed by WH1021 (6.5). However, minimum nitrogen content was observed in WH711 (8.8) followed by WH1184 (9.1) under TS condition while in LS condition, WH711 (7.2) followed by WH1184 (7.9) showed minimum nitrogen content. In very late sown conditions the minimum nitrogen content was observed in WH147 (4.7) followed by WH1105 (5.3).

In Leaves, maximum nitrogen content was observed in wheat genotype HD2967 (12.39) followed by WH1021 (11.60) under TS while in HD2967 (10.80) followed by WH1021 (10.10) under LS condition. In very late sown conditions the maximum nitrogen content was observed in HD2967 (7.51) followed by WH1021 (6.91). However, minimum nitrogen content was observed in WH1184 (9.51) followed by WH711 (10.10) under TS condition while in LS condition, WH1184 (7.90) followed by WH711 (8.40) showed minimum nitrogen content. In very late sown conditions the minimum nitrogen content was observed in WH1105 (5.11) followed by WH711 (5.31).

Table 4.8: Nitrogen content (N) (%) of wheat genotypes in leaves, stem and root under timely, late and very late sown conditions.

Wheat Genotype	N content (%)											
	Leaves				Stem				Root			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	10.60	8.70	6.31	**8.53**	9.60	8.30	4.70	**7.53**	1.22	1.01	0.81	**1.01**
WH711	10.10	8.40	5.31	**7.94**	8.80	7.21	5.98	**7.33**	1.26	1.04	0.61	**0.97**
WH1105	10.90	9.00	5.11	**8.34**	10.40	8.99	5.31	**8.23**	1.35	1.12	0.68	**1.05**
WH1184	9.51	7.90	5.71	**7.71**	9.10	7.90	5.67	**7.56**	1.20	1.00	0.72	**0.97**
HD2967	12.40	10.80	7.51	**10.24**	11.80	10.40	7.70	**9.97**	1.60	1.39	1.12	**1.37**
WH1021	11.60	10.10	6.91	**9.54**	10.00	8.72	6.51	**8.41**	1.32	1.15	0.92	**1.13**
Mean	**10.85**	**9.27**	**6.14**		**9.95**	**8.59**	**5.98**		**1.33**	**1.12**	**0.81**	
C.D at 5 %	G =0.199, E =0.281, G x E = 0.487				G =0.587, E =0.83, G x E = NS				G =0.03, E =0.04, G x E = 0.61			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.2.2.4 Phosphorous (P) Content in Leaves, Stem and Root

Table 4.9 demonstrates the phosphorous content of six wheat genotypes in leaves, stem and roots, and under TS, LS and VLS condition. In Leaves, maximum phosphorous content was observed in wheat genotype HD2967 (4.89) followed by WH1021 (4.75) under TS while in HD2967 (4.20) followed by WH1021 (4.15) under LS condition. In very late sown conditions the maximum phosphorous content was observed in HD2967 (2.75) followed by WH1021 (2.65). However, minimum phosphorous content was observed in WH711 (3.80) followed by WH1184 (3.89) under TS condition while in LS condition, WH711 (3.20) followed by WH1184 (3.40) showed minimum phosphorous content. In very late sown conditions the minimum phosphorous content was observed in WH1184 (2.00) followed by WH711 (2.21).

In Roots, maximum phosphorous content was observed in wheat genotype HD2967 (2.00) followed by WH1021 (1.80) and WH 1105 (1.5) under TS while in HD2967 (1.80) followed by WH1021 (1.65) under LS condition. In very late sown conditions the maximum phosphorous content was again observed in HD2967 (1.50) followed by WH1021 (1.38). However, minimum phosphorous content was observed in WH147 i.e.1.00, 0.90 and 0.70 under TS, LS and VLS conditions respectively.

In Stem, maximum phosphorous content was observed in wheat genotype WH1105 (11.99) followed by WH1021 (11.90) under TS while in HD2967 (10.60) followed by WH1021 (10.50) under LS condition. In very late sown conditions the maximum phosphorous content was observed in HD2967 (8.70) followed by WH1105 (8.05). However, minimum phosphorous content was observed in WH711 (11.20) followed by WH147 (11.40) under TS condition while in LS condition, WH1184 (9.50) followed by WH711 (9.80) showed minimum phosphorous content. In very late sown conditions the minimum phosphorous content was observed in WH1184 (7.30) followed by WH711 (7.70).

Table 4.9: Phosphorus content (P) (%) of wheat genotypes in leaves, stem and root under timely, late and very late sown conditions

Wheat Genotype	**P content (%)**											
	Leaves				**Stem**				**Root**			
	TS	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**
WH147	4.00	3.40	2.30	**3.23**	11.40	10.00	8.00	**9.80**	1.00	0.90	0.70	**0.87**
WH711	3.80	3.20	2.21	**3.07**	11.20	9.80	7.70	**9.57**	1.20	1.10	0.91	**1.07**
WH1105	4.20	3.60	2.45	**3.42**	12.00	10.40	8.05	**10.15**	1.50	1.35	1.10	**1.32**
WH1184	3.90	3.40	2.00	**3.10**	11.20	9.50	7.30	**9.33**	1.10	0.95	0.74	**0.93**
HD2967	4.89	4.20	2.75	**3.95**	11.80	10.60	8.70	**10.37**	2.00	1.80	1.50	**1.77**
WH1021	4.75	4.15	2.65	**3.85**	11.90	10.50	7.40	**9.93**	1.80	1.65	1.38	**1.61**
Mean	**4.26**	**3.66**	**2.39**		**11.58**	**10.13**	**7.86**		**1.43**	**1.29**	**1.06**	
C.D at 5 %	G =0.077, E =0.108, G x E = 0.188				G =0.194, E =0.274, G x E = 0.475				G =0.02, E =0.03, G x E = 0.06			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.2.2.4 Potassium (K) Content in Root, Stem and Leaves

Table 4.10 demonstrates the potassium content of six wheat genotypes in roots, stem and leaves under TS, LS and VLS condition. In Roots, maximum potassium content was observed in wheat genotype HD2967 (1.60) followed by WH1021 (1.54) under TS while in HD2967 (1.40) followed by WH1021 (1.30) under LS condition. In very late sown conditions the maximum potassium content was observed in HD2967 (1.10) followed by WH1021 (0.98). However, minimum potassium content was observed in WH1184 (1.00) followed by WH711 (1.20) under TS condition while in LS condition, WH1184 (0.85) followed by WH711 (0.95) showed minimum potassium content. In very late sown conditions the minimum potassium content was observed in WH1184 (0.68) followed by WH711 (0.74).

Table 4.10 Potassium content (K) (%) of wheat genotypes in leaves, stem and roots under timely, late and very late sown conditions

Wheat Genotype	**K content (%)**											
	Leaves				**Stem**				**Root**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	16.50	13.20	9.80	**16.50**	55.40	44.32	36.00	**45.24**	1.40	1.15	0.92	**1.16**
WH711	15.20	12.80	8.80	**15.20**	53.60	41.80	34.20	**43.20**	1.20	0.95	0.74	**0.96**
WH1105	15.00	12.40	9.10	**15.00**	53.00	42.20	34.80	**43.33**	1.30	1.05	0.85	**1.07**
WH1184	14.40	11.10	8.90	**14.40**	48.00	38.60	31.20	**39.27**	1.00	0.85	0.68	**0.84**
HD2967	17.00	14.50	12.40	**17.00**	58.00	45.80	38.50	**47.43**	1.60	1.40	1.10	**1.37**
WH1021	15.80	13.90	11.20	**15.80**	55.00	43.00	36.80	**44.93**	1.55	1.30	0.98	**1.28**
Mean	**15.65**	**12.98**	**10.03**		**53.83**	**42.62**	**35.25**		**1.34**	**1.12**	**0.88**	
C.D at 5 %	G =0.023, E =0.033, G x E = 0.57				G =0.637, E =0.901, G x E = NS				G =0.225, E =0.318, G x E = 0.552			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

In Stem, maximum potassium content was observed in wheat genotype HD2967 (58.00) followed by WH147 (55.40) under TS while in HD2967 (45.80) followed by WH147

(44.32) under LS condition. In very late sown conditions the maximum potassium content was observed in HD2967 (38.50) followed by WH1021 (36.80). However, minimum potassium content was observed in WH1184 (47.99) followed by WH1105 (53.00) under TS condition while in LS condition, WH1184 (38.60) followed by WH711 (41.80) showed minimum potassium content. In very late sown conditions the minimum potassium content was observed in WH1184 (31.20) followed by WH711 (34.20).

In Leaves, maximum potassium content was observed in wheat genotype HD2967 (17.00) followed by WH147 (16.50) under TS while in HD2967 (14.50) followed by WH1021 (13.90) under LS condition. In very late sown conditions the maximum potassium contentwas observed in HD2967 (12.40) followed by WH1021 (11.20). However, minimum potassium content was observed in WH1184 (14.40) followed by WH1105 (15.00) under TS condition while in LS condition, WH1184 (11.10) followed by WH1105 (12.40) showed minimum potassium content. In very late sown conditions the minimum potassium content was observed in WH1184 (8.90) followed by WH1105 (9.10).

4.2.2 Observations on flag leaf

4.2.2.1 Photosynthetic rate (μ mole $m^{-2}s^{-1}$)

Photosynthetic rate was reduced in all genotypes under VLS and LS as compared to TS conditions (Table 4.11). At seven days after anthesis (DAA), Maximum photosynthetic rate was observed in genotype WH1021 (18.98) followed by HD2967 (18.62) and WH1184 (18.31) under TS condition and in WH1021 (17.27) followed by HD2967 (16.29) and WH1184 (15.26) under LS condition and under VLS condition, HD2967 (15.87) followed by WH711 (15.17) showed maximum photosynthetic rate. However, WH147 (15.29) followed by WH 711 (15.67) showed minimum photosynthetic rate under TS and in WH147 (11.02) followed by WH711 (12.17) under LS condition while under VLS condition, WH147 (10.78) followed by WH711 (11.89) showed minimum photosynthetic rate.

Table 4.11 Photosynthetic rate (μ mol $m^{-2}s^{-1}$) of wheat genotypes at 7 and 14 DAA under timely, late and very late sown conditions

Wheat genotype	**Photosynthetic rate**							
	7DAA				**14DAA**			
	TS	**LS**	**VLS**	**Mean**	**TS**	**LS**	**VLS**	**Mean**
WH147	15.29	11.02	10.78	**12.36**	10.85	7.02	4.21	**7.36**
WH711	15.67	12.17	11.89	**13.24**	9.80	8.17	5.63	**7.87**
WH1105	17.66	15.24	13.07	**15.32**	12.24	11.47	6.07	**9.93**
WH1184	18.31	15.26	14.44	**16.00**	13.17	11.64	8.44	**11.08**
HD2967	18.62	16.29	15.87	**16.93**	13.91	10.26	9.06	**11.08**
WH1021	18.98	17.27	15.47	**17.24**	14.66	11.64	9.24	**11.85**
Mean	**17.42**	**14.54**	**13.59**		**12.44**	**10.03**	**7.11**	
C.D at 5 %	G =0.28, E =0.40, G x E = 0.70				G =0.27, E =0.38, G x E = 0.66			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

At 14 DAA, Maximum photosynthetic rate was observed in genotype WH1021 (14.66) followed by HD2967 (13.91) under TS condition and in WH1021 (11.64) under LS condition and under VLS condition, WH1021 (9.24) followed by HD2967 (14.06) showed maximum photosynthetic rate. However, WH147 minimum photosynthetic rate of 15.35, 11.02 and 10.39 µ mol m^{-2} s^{-1} respectively under TS, LS and VLS conditions.

4.2.2.2 Transpiration rate (mmole $m^{-2}s^{-1}$)

Transpiration rate of wheat genotypes under TS, LS and VLS condition is shown in Table 4.12. The transpiration rate ranged from 2.99 to 4.13 under TS, 1.73 to 2.99 under LS and 1.54 to 2.76 VLS condition at 7 DAA. Maximum transpiration rate was observed in HD2967 at 7DAA (4.13) and 14DAA (3.18) under TS. However, minimum transpiration rate was observed in WH147 at 7DAA (2.99) and 14DAA (2.81) under TS. Similar trend was observed under LS and VLS conditions for maximum and minimum transpiration rate.

Table 4.12: Transpiration rate (mmol $m^{-2}s^{-1}$) at 7 and 14 DAA in wheat genotypes under timely, late and very late sown conditions

Wheat genotype	**Transpiration rate**							
	7DAA				**14DAA**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	2.99	1.73	1.54	**2.09**	2.81	2.14	1.86	**2.27**
WH711	3.11	2.18	2.07	**2.45**	3.03	2.26	2.04	**2.44**
WH1105	3.79	2.65	1.90	**2.78**	3.72	2.79	2.39	**2.97**
WH1184	3.09	2.17	1.89	**2.38**	2.73	2.23	2.06	**2.34**
HD2967	4.13	2.99	2.76	**3.29**	3.83	3.18	2.94	**3.32**
WH1021	3.91	2.76	2.54	**3.07**	2.77	2.29	2.09	**2.38**
Mean	**3.50**	**2.41**	**2.12**		**3.15**	**2.48**	**2.23**	
C.D at 5 %	G =0.04, E =0.06, G x E = 0.10				G =0.04, E =0.06, G x E = 0.11			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.2.2.3 Stomatal conductance (mmole $m^{-2}s^{-1}$)

Stomatal conductance of wheat genotypes under TS, LS and VLS condition is shown in Table 4.13. The stomatal conductance ranged from 0.33 to 0.44 under TS, 0.28 to 0.42 under LS and 0.20 to 0.38 VLS condition at 7 DAA. Maximum stomatal conductance was observed in HD2967 at 7DAA (0.44) and 14DAA (0.36) under TS. However, minimum stomatal conductance was observed in WH147 at 7DAA (0.33) and in WH1105 (0.23) at 14DAA under TS. Reduction in stomatal conductance was observed under LS and VLS in all genotypes.

4.2.2.4 Chlorophyll content (SPAD)

Table 4.14 demonstrates the chlorophyll content of six wheat genotypes under TS, LS and VLS condition. There was decline in chlorophyll content under LS and VLS condition. Maximum chlorophyll content at 7 DAA was observed in genotype HD2967 (48.07) followed by WH1021 (44.90) under TS condition and in HD2967 (46.63) followed by WH1021

(43.37) under LS condition while under VLS condition, HD2967 (39.82) followed by WH1021 (32.60) showed maximum chlorophyll content. However, WH711 (39.83) followed by WH1184 (41.07) showed minimum chlorophyll content under TS and WH711 (34.88) followed by WH1105 (35.47) under LS condition while under VLS condition, WH147 (26.60) followed by WH711 (27.53) showed minimum chlorophyll content (Table 4.14).

Table 4.13 Stomatal conductance (m mol m^{-2} s^{-1}) at 7 and 14 DAA in wheat genotypes under timely, late and very late sown conditions

Wheat genotype	Stomatal conductance							
	7DAA				14DAA			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	0.33	0.28	0.21	**0.27**	0.30	0.20	0.15	**0.22**
WH711	0.35	0.31	0.20	**0.29**	0.31	0.22	0.19	**0.24**
WH1105	0.43	0.39	0.25	**0.36**	0.23	0.19	0.15	**0.19**
WH1184	0.42	0.39	0.27	**0.36**	0.28	0.25	0.19	**0.24**
HD2967	0.44	0.42	0.38	**0.41**	0.36	0.33	0.29	**0.33**
WH1021	0.39	0.37	0.31	**0.36**	0.32	0.28	0.22	**0.27**
Mean	**0.39**	**0.36**	**0.27**		**0.30**	**0.25**	**0.20**	
C.D at 5 %	G =0.01, E =0.01, G x E = 0.02				G =0.01, E =0.01, G x E = 0.01			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

At 14 DAA, maximum chlorophyll content was observed in genotype HD2967 (42.10) followed by WH1021 (37.97) under TS condition and in HD2967 (40.17) followed by WH1021 (35.78) under LS condition while under VLS condition, HD2967 (34.60) followed by WH1021 (30.83) showed maximum chlorophyll content. However, WH147 (33.20) followed by WH1184 (33.67) showed minimum chlorophyll content under TS and WH147 (27.97) followed by WH711 (29.93) under LS condition while under VLS condition, WH147 (22.87) followed by WH711 (23.27) showed minimum chlorophyll content (Table 4.14).

Table 4.14: Chlorophyll content (SPAD) at 7 and 14 DAA at 7 and 14 DAA in wheat genotypes under timely, late and very late sown conditions

Wheat genotype	chlorophyll content (SPAD units)							
	7DAA				14DAA			
	TS	LS	VLS	Mean	TS	LS	VLS	Mean
WH147	41.40	35.70	26.60	**34.57**	33.20	27.97	22.87	**28.01**
WH711	39.83	34.88	27.53	**34.08**	36.40	29.93	23.27	**29.87**
WH1105	44.07	35.47	29.68	**36.40**	35.10	30.77	27.43	**31.10**
WH1184	41.07	38.90	27.74	**35.90**	33.67	30.37	25.90	**29.98**
HD2967	48.07	46.63	39.82	**44.84**	42.10	40.17	34.60	**38.96**
WH1021	44.90	43.37	32.60	**40.29**	37.97	35.78	30.83	**34.86**
Mean	**43.22**	**39.16**	**30.66**		**28.01**	**32.50**	**27.48**	
C.D at 5 %	G =2.91, E =4.11, G x E = NS				G =2.38, E =3.37 G x E = NS			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.2.2.4 Chlorophyll Fluorescence

Table 4.15 demonstrates the chlorophyll fluorescence of six wheat genotypes under TS, LS and VLS condition. There was decline in chlorophyll fluorescence under LS and VLS from TS condition. Maximum chlorophyll fluorescence at 7 DAA was observed in genotype HD2967 (0.819) followed by WH1021 (0.816) under TS condition and in HD2967 (0.816) followed by WH1021 (0.800) under LS condition while under VLS condition, HD2967 (0.811) followed by WH1021 (0.79) showed maximum chlorophyll fluorescence. However, WH147 (0.79) followed by WH711 (0.80) showed minimum chlorophyll fluorescence under TS and WH147 (0.72) followed by WH711 (0.74) under LS condition while under VLS condition, WH1105 (0.76) followed by WH147 (0.78) showed minimum chlorophyll fluorescence (Table 4.15).

Table 4.15: Chlorophyll fluorescence (Fv/Fm) at 7 and 14 DAA in different wheat genotypes under timely, late and very late sown conditions

Wheat genotype	**Chlorophyll fluorescence (Fv/Fm)**							
	7DAA				**14DAA**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	0.79	0.72	0.78	**0.76**	0.80	0.75	0.74	**0.76**
WH711	0.80	0.74	0.79	**0.78**	0.80	0.76	0.74	**0.77**
WH1105	0.81	0.77	0.76	**0.78**	0.76	0.72	0.69	**0.72**
WH1184	0.81	0.78	0.78	**0.79**	0.78	0.76	0.71	**0.75**
HD2967	0.82	0.82	0.81	**0.82**	0.80	0.79	0.79	**0.79**
WH1021	0.82	0.80	0.79	**0.80**	0.77	0.75	0.74	**0.75**
Mean	**0.81**	**0.77**	**0.79**		**0.78**	**0.76**	**0.73**	
C.D at 5 %	G =0.02, E =0.02, G x E = NS				G =0.01, E =0.02, G x E = 0.03			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

At 14 DAA, maximum chlorophyll fluorescence was observed in genotype HD2967 (0.80) followed by WH711 (0.799) under TS condition and in HD2967 (0.79) followed by WH711 (0.76) under LS condition while under VLS condition, HD2967 (0.79) followed by WH1021 (0.74) showed maximum chlorophyll fluorescence. However, WH1105 (0.761) followed by WH1021 (0.768) showed minimum chlorophyll fluorescence under TS and WH1105 (0.724) followed by WH147 (0.754) under LS condition while under VLS condition, WH1184 (0.713) followed by WH711 (0.737) showed minimum chlorophyll fluorescence.

4.2.2.4 Anthocynin Content

Table 4.16 demonstrates the anthocynin content of six wheat genotypes under TS, LS and VLS condition. Maximum anthocynin content at 7 DAA was observed in genotype HD2967 (0.107) followed by WH1021 (0.099) under TS condition and in HD2967 (0.119) followed by WH1021 (0.112) under LS condition while under VLS condition, HD2967 (0.163) followed by WH1021 (0.158) showed maximum anthocynin content. However, WH147 (0.072) followed by WH711 (0.079) showed minimum anthocynin content under TS and WH147 (0.098) followed by WH711 (0.103) under LS condition while under VLS condition, WH147 (0.128) followed by WH711 (0.142) showed minimum anthocynin content.

At 14 DAA, maximum anthocynin content was observed in HD2967 (0.187) followed by WH1021 (0.176) under TS condition and in HD2967 (0.203) followed by WH1021 (0.192) under LS condition while under VLS condition, HD2967 (0.215) followed by WH1021 (0.204) showed maximum anthocynin content. However, WH147 (0.150) followed by WH711 (0.156) showed minimum anthocynin content under TS and WH147 (0.167) followed by WH711 (0.175) under LS condition while under VLS condition, WH147 (0.177) followed by WH711 (0.190) showed minimum anthocynin content (Table 4.16).

Table 4.16: Anthocyanin content at 7 and 14 DAA in different wheat genotypes under of timely, late and very late sown conditions on

Wheat genotype	**Anthocyanin**							
	7DAA				**14DAA**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	0.072	0.098	0.128	0.099	0.150	0.167	0.177	0.165
WH711	0.079	0.103	0.142	0.108	0.156	0.175	0.190	0.174
WH1105	0.084	0.106	0.151	0.114	0.165	0.185	0.195	0.182
WH1184	0.096	0.108	0.154	0.119	0.170	0.189	0.196	0.185
HD2967	0.107	0.119	0.163	0.130	0.187	0.203	0.215	0.202
WH1021	0.099	0.112	0.158	0.123	0.176	0.192	0.204	0.191
Mean	0.090	0.108	0.149		0.167	0.185	0.196	
C.D at 5 %	G =0.002, E =0.002, G x E = 0.004				G =0.004, E =0.006 G x E = NS			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

4.3 Yield and yield attributes

Yield and yield attributes are shown in Table 4.17. Heading was found earliest in genotypes WH1184 at 86.3, 75.7 and 70.2 DAS under TS, LS and VLS conditions. However, late heading was found in genotypes WH1021 (103.3) under TS condition and in WH147 (87.3) under LS conditions while under VLS conditions, genotype WH147 (76.7) show late heading.

Anthesis was found earliest in genotypes WH1184 at 90.2, 79.0 and 72.0 DAS under TS, LS and VLS conditions. However, maximum number of days to anthesis was found in genotypes WH1021 107.33 days under TS condition, WH147 (90.2) days under LS and 78.2 days under VLS conditions.

Earliest days to maturity was found in genotypes WH1184 (114.3 days) under TS condition and in WH1184, (105.6 days) under LS condition and WH147 (100.1 days) under VLS (Table 4.17). However, late maturity was found in genotypes WH1021 (131.3) under TS, (116.0 days) under LS condition while 110.6 days under VLS conditions.

Wheat genotypes WH1021 showed maximum plant height under TS (67.87cm) and

LS (60.6cm) condition while under VLS conditions, genotype WH1021 (55.40cm) showed maximum plant height (Table 4.17). However, minimum plant height was found in genotypes WH1105 (54.80) under TS condition and in WH711 (47.00) under LS condition while under VLS conditions, genotype WH711 (44.20) show minimum plant height (Table 4.17).

Maximum number of spikelets per spike were recorded in genotypes HD2967 (16.00) under TS condition and in HD2967 (15.67) under LS condition while under VLS conditions, genotype HD2967 (14.33) showed maximum number of spikelets per spike (Table 4.17). However, minimum number of spikelets per spike were found in genotypes WH147 (11.00) under TS condition and in WH147 (9.67) under LS condition while under VLS conditions, genotype WH147 (9.00) show minimum number of spikelets per spike (Table 4.17).

Maximum spike length was recorded in genotypes HD2967 (9.00) under TS condition and in HD2967 (8.33) under LS condition while under VLS conditions, genotype HD2967 (7.40) show maximum spike length (Table 4.17). However, minimum spike length was found in genotypes WH147 (6.20) under TS condition and in WH147 (5.90) under LS condition while under VLS conditions, genotype WH147 (5.53) show minimum spike length (Table 4.17).

Maximum number of grains per spike were recorded in genotypes HD2967 (33.00) under TS condition and in HD2967 (31.33) under LS condition while under VLS conditions, genotype HD2967 (27.00) show maximum number of grains per spike. However, minimum number of grains per spike were found in genotypes WH711 (25.00) under TS condition and in WH147 (22.33) under LS condition while under VLS conditions, genotype WH147 (12.33) show minimum number of grains per spike (Table 4.17).

Maximum biomass (g) was recorded in genotype WH711 (2.52) under TS condition and in HD2967 (1.99) under LS condition while under VLS conditions, genotype HD2967 (1.73) show maximum biomass (Table 4.17). However, minimum biomass was recored in genotype WH1184 (1.35) under TS condition and in WH1184 (1.05) under LS condition while under VLS conditions, genotype WH1184 (1.01) show minimum biomass (Table 4.17).

Maximum 1000 grains weight (g) was recorded in genotypes HD2967 (43.20) under TS condition and in HD2967 (35.60) under LS condition while under VLS conditions, genotype HD2967 (31.10) show maximum 1000 grains weight. However, minimum 1000 grains weightwas recored in genotypes WH147 (27.80) under TS condition and in WH147 (20.80) under LS condition while under VLS conditions, genotype WH147 (17.30) show minimum 1000 grains weight (Table 4.17).

Maximum grains weight/ plant (g) was recorded in genotype HD2967 (1.07) under TS condition and in HD2967 (0.93) under LS condition while under VLS conditions, genotype HD2967 (0.77) showed maximum grains weight per plant. However, minimum grains weight per plant was recored in genotypes WH147 (0.67) under TS condition and in

Table 4.17: Days to heading, days to anthesis, days to maturity,plant height (cm), spike length (cm), no. of spikelets/spike, biomass (g/plant), 1000 grains weight (g) of wheat genotypes under timely, late and very late sown conditions.

Wheat Genotype	**Days to Heading**				**Days to anthesis**				**Days to maturity**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	99.3	87.3	76.7	**87.8**	103.3	90.2	78.2	**90.6**	127.3	110.3	100.1	**111.7**
WH711	94.3	76.0	71.3	**79.6**	98.1	79.2	72.1	**83.2**	122.3	106.0	104.0	**110.8**
WH1105	90.3	76.0	70.7	**78.0**	94.2	79.2	71.2	**81.2**	118.3	106.0	103.6	**109.3**
WH1184	86.3	75.7	70.2	**76.4**	90.2	79.0	72.0	**79.4**	114.3	105.6	100.3	**106.7**
HD2967	95.7	80.0	70.8	**82.0**	99.1	84.4	72.2	**85.2**	123.6	110.0	106.3	**113.3**
WH1021	103.3	86.0	74.7	**88.0**	107.3	90.1	76.3	**91.2**	131.3	116.0	110.6	**119.3**
Mean	**94.9**	**80.2**	**70.8**		**98.7**	**83.7**	**73.0**		**122.9**	**109.0**	**103.7**	
C.D at 5 %	G =0.81, E =1.15, G x E = 1.99				G =0.17, E =0.17, G x E = NS				G =0.29, E =0.29, G x E = NS			
	Plant height (cm)				**Spike length (cm)**				**No. of spikelets per spike**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	66.1	55.1	50.5	57.3	6.2	5.9	5.5	**5.9**	11.0	9.7	9.0	**9.9**
WH711	57.1	47.0	44.2	49.4	6.4	6.2	5.8	**6.1**	12.1	11.2	9.0	**10.8**
WH1105	54.8	47.6	42.2	48.2	6.6	6.4	5.9	**6.3**	14.3	12.3	9.7	**12.1**
WH1184	61.0	53.0	51.3	55.1	7.3	6.8	6.2	**6.8**	15.0	14.3	11.7	**13.7**
HD2967	59.1	52.8	50.4	54.1	9.0	8.3	7.4	**8.2**	16.0	15.7	14.3	**15.3**
WH1021	67.9	60.6	55.4	61.3	7.7	7.5	6.7	**7.3**	16.0	15.0	12.3	**14.4**
Mean	**61.0**	**52.7**	**49.0**		**7.2**	**6.9**	**6.3**		**14.6**	**13.0**	**11.0**	
C.D at 5 %	G =0.66, E =0.93, G x E = 1.61				G =0.11, E =0.15, G x E = 0.26				G =0.92, E =1.31, G x E = NS			
	Biomass (g)/plant				**1000 grain weight (g)**				**No. of Grains/Spikelet**			
	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**	TS	LS	VLS	**Mean**
WH147	2.09	1.47	1.27	**2.09**	27.8	20.8	17.3	**22.0**	26.7	22.3	12.3	**26.7**
WH711	2.52	1.97	1.34	**2.52**	30.5	23.7	20.1	**24.8**	25.0	24.7	15.3	**25.0**
WH1105	1.85	1.40	1.12	**1.85**	34.9	27.1	23.3	**28.4**	26.0	24.3	14.3	**26.0**
WH1184	1.35	1.05	1.01	**1.35**	34.7	27.6	23.7	**28.6**	29.3	28.3	20.7	**29.3**
HD2967	2.21	1.99	1.73	**2.21**	43.2	35.6	31.1	**36.6**	33.0	31.3	27.0	**33.0**
WH1021	2.07	1.68	1.48	**2.07**	35.8	28.8	24.0	**29.5**	29.7	27.3	22.3	**29.7**
Mean A	**2.01**	**1.59**	**1.32**		**34.5**	**27.3**	**23.3**		**22.3**	**26.4**	**18.7**	
C.D at 5 %	G =0.27, E =0.39, G x E = 0.67				G =1.24, E =1.75, G x E = 3.03				G =1.79, E =2.54, G x E = NS			

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

WH147 (0.54) under LS condition while under VLS conditions, genotype WH711 (0.31) show minimum grains weight per plant (Table 4.18). Minimum HSI was recorded in genotype WH1021 (0.70) under TS condition and in HD2967 (0.67) under LS condition while under VLS conditions, genotype HD2967 (0.70) show minimum grain yield (Table 4.18).

Minimum HSI was recorded in WH1021 (0.70) followed by HD2967 (0.72) under LS conditions. However under VLS conditions genotype minimum HSI was recorded HD2967 (0.70) followed by WH1021 (0.76.)

Correlation analysis: Correlation is a statistical measure that indicates the extent to which two or more variables fluctuate together. Photosynthetic rate is an important trait to determine yield and is affected by a number of component traits. Table 4.19 represents the correlation of photosynthetic rate and NPK content in leaf, stem and roots wheat varieties under timely, late and very late environment. Photosynthesis and NPK correlation analysis revealed the negative correlation of photosynthesis rate with K content in leaf and stem under LS conditions and with P content in stem under VLS conditions. Correlation varied with sowing conditions indicates the different requirement of NPK. As under LS conditions more K is required while under VLS more P is required.

Table 4.18: Grain Yield (g/plant) and Heat Susceptibility Index (HSI) of different wheat genotypes under timely, late and very late sown conditions

Wheat Genotype	**Yield/plant (g)**				**Heat Susceptibility Index**		
	TS	LS	VLS	**Mean**	LS	VLS	**Mean**
WH147	0.670	0.539	0.334	0.514	1.04	1.20	1.12
WH711	0.680	0.563	0.310	0.518	0.92	1.30	1.11
WH1105	0.849	0.708	0.472	0.676	0.88	1.06	0.97
WH1184	0.840	0.704	0.521	0.688	0.86	0.91	0.89
HD2967	1.072	0.926	0.774	0.924	0.72	0.67	0.70
WH1021	0.906	0.786	0.595	0.762	0.70	0.82	0.76
Mean	0.836	0.704	0.501		0.85	1.00	
C.D at 5 %	G =0.81, E =1.15, G x E = 1.99						

*TS- Timely sown; LS- Late sown; VLS-Very late sown; G- Genotype; E- Environment; DAS- Days after sowing

Table 4.19 Correlation of photosynthetic rate and NPK content in leaf, stem and roots wheat varieties under timely, late and very late environment

	A	N leaf	N stem	N Root	P Leaf	P stem	P Root	K Leaf	K Stem	K Root
TIMELY SOWN										
A	1.000									
N Leaf	0.555	1.000								
N Stem	0.573	0.898*	1.000							
N Root	0.469	0.877*	0.936**	1.000						
P Leaf	0.799	0.939**	0.847*	0.810	1.000					
P Stem	0.588	0.771	0.740	0.609	0.762	1.000				
P Root	0.721	0.901*	0.829*	0.874*	0.945**	0.776	1.000			
K Leaf	0.152	0.785	0.666	0.631	0.626	0.322	0.473	1.000		
K Stem	0.089	0.858*	0.670	0.694	0.659	0.492	0.601	0.924**	1.000	
K Root	0.424	0.947**	0.747	0.698	0.856*	0.691	0.755^{NS}	0.865*	0.924**	1.000
LATE SOWN										
A	1.000									
N Leaf	0.223	1.000								
N Stem	0.326	0.854*	1.000							
N Root	0.273	0.919**	0.903*	1.000						
P Leaf	0.489	0.938**	0.835*	0.838*	1.000					
P Stem	0.249	0.913*	0.815*	0.797	0.838*	1.000				
P Root	0.474	0.940**	0.790	0.907*	0.925**	0.879*	1.000			
K Leaf	-0.199	0.898*	0.635	0.751	0.727	0.812*	0.745	1.000		
K Stem	-0.381	0.786	0.677	0.686	0.564	0.765	0.566	0.922**	1.000	
K Root	0.021	0.959**	0.804	0.810	0.875*	0.880*	0.810	0.945**	0.882*	1.000
VERY LATE SOWN										
A	1.000									
N Leaf	0.564	1.000								
N Stem	0.780	0.687	1.000							
N Root	0.592	0.968**	0.729	1.000						
P Leaf	0.411	0.707	0.652	0.780	1.000					
P Stem	-0.085	0.414	0.400	0.561	0.597	1.000				
P Root	0.674	0.645	0.844*	0.728	0.919**	0.450	1.000			
K Leaf	0.594	0.955**	0.783	0.979**	0.870*	0.554	0.827*	1.000		
K Stem	0.157	0.752	0.539	0.779	0.926**	0.699	0.745	0.855*	1.000	
K Root	0.308	0.846*	0.572	0.894*	0.933**	0.687	0.768	0.930**	0.964**	1.000

*, ** Significant at 5% and 1% level of significance, respectively, A- Photosynthesis rate

CHAPTER-V

DISCUSSION

Wheat is one of the most important cereal crops, which is considered as the earliest domesticated food crop (Curtis *et al.*, 2002). In the world, it covers most of total harvested area (Leff *et al.,* 2004). It is main *Rabi* crop and is dependent upon sowing time and varietal selection for its production potential. Wheat has shorter crop period and faces high temperature at reproductive phase due to delayed sowing in crop rotation i.e., cotton-wheat, paddy-wheat, rice-wheat (Singh and Jaiswal, 2013). Being a crucial environmental factor, temperature reduces crop yield and productivity worldwide. High frequency of heat waves, heavy precipitation, hot days and low frequency of cold waves are major contributors for escalating global temperature (Mishra *et al.*, 2017). Reduced productivity and grain yield is significantly observed under the effect of devastating abiotic stresses including high temperature (Parent *et al.,* 2010). Global warming due to present climate change adversely affects wheat production all over the world, which increased food uncertainty and shortage (Ortiz *et al.*, 2008).Wheat yield can decrease by 3-10 % with every 1°C rise in temperature above the optimum limit (Gibson *et al.*, 1999; You *et al.*, 2009; Modarresi *et al.*, 2010). High temperature stress cause alterations in various physiological, biochemical and molecular processes of crop plants resulted in reduction of total crop yield. The major contributors for escalating global temperature include high frequency of heat waves, heavy precipitation, hot days and low frequency of cold waves (Mishra *et al.* 2017). Various physiological, molecular and cellular effects have been seen on the leaves, stem and root growth, which lead to decrease in productivity and quality of plants produce (Vollenweider and Goerg 2005). Identification of stable genotypes, adaptable to wide range of environments have considerable significance in bread wheat improvements (Kant *et al.* 2014).

The impact of high temperature stress on crop depends on duration of stress and crop stage (Wahid *et al.*, 2007; Djanaguiraman and Prasad, 2010). There is paramount need to develop different cultivars able to tolerate heat stress at different vegetative and reproductive stages of plant growth (Irfan and Imran, 2018). The present investigation entitled “Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions” has been conducted. The findings and important results obtained in the present investigation have been discussed below under appropriate headings:

5.1 Physiological parameters affected by high temperature stress condition

5.2 Growth parameters in response to high temperature condition

5.3 Yield parameters in response to high temperature condition

5.1 Physiological parameters affected by high temperature stress condition

Monitored by infrared temperature sensors, canopy temperature can provide continuous information on water status, water use and how a plant is functioning metabolically. It can be used for measuring heat tolerance under high temperature conditions as CT is negatively correlated with yield. Cooler is the canopy, more are the yield benefits under high temperature stress (Reynolds *et al.,* 1994; Munjal and Rana 2003; Gutierrez *et al.*, 2010; Pinto *et al.,* 2010).

According to Saxena *et al.* (2016) canopy temperature depression is affected by a number of physiological processes directly or indirectly and can be used as a good indicator of genotype fitness in a given environment. High canopy temperature may be indicative of a high demand for photo-assimilation whereas low canopy temperature is an indicator of deep rootedness of the plant for tapping moisture from lower soil horizons, thus meeting the transpiration demands under high temperature condition (Reynolds 2002). According to Kumar *et al.* (2016) percent decrease in canopy temperature depression (CTD) from anthesis to 15 days after anthesis (DAA) was highest (87.57 %) for genotype UP2338, followed by JOB666 (83.03 %) indicating susceptibility of genotypes for heat tolerance however lowest CTD (30.67%) was observed for variety HD2967 indicating heat tolerant nature of genotype. The results of present investigation for canopy temperature (Tables 4.1) showed variation among different wheat genotypes at different sowing conditions. Minimum percentage reduction was observed in WH1105 (0.74 %) among all genotypes in different sowing conditions. The results of present investigation are in corroboration with study of Rehman *et al.* 2021; Karimizadeh and Mohammadi 2011; Ray and Ahmed 2015.

Sharma *et al.* (2018) observed that as the crop matures, the CT depression value goes on decreasing because canopy gets warmer and results in lower photosynthetic assimilation which leads to lower yield. The heat tolerant cultivars showed higher CTD than the heat sensitive cultivars under normal and stress conditions indicating their higher ability to maintain low canopy temperature than heat sensitive cultivars (Gare *et al.*, 2018). Overall, cooler CT was favorable for higher yield and this association was stronger and more consistent under heat stress (Shehrawat and Kumar, 2021). Gautaum *et al.* (2015) also concluded that the genotypes which showed low CT have high yield as compared to those which showed high CT under late and very late sown condition. This showed that CT is negatively correlated with yield and yield attributes and can be used as an important selection parameter for high temperature tolerant variety (Mansouri *et al.,* 2018; Manjunatha *et al.,* 2020).

Another most important key physiological process is photosynthesis that is affected by heat stress. It is one of the major parameter which control biomass production and grain yield. High temperature stress in wheat during vegetative and reproductive phase caused a sharp decline in photosynthetic rate (Sunita and Munjal, 2017). Optimum temperature for photosynthesis in wheat is 20°C to 30°C which declined rapidly at higher >30°C temperature. Khan *et al.* (2021) reported high temperature (32/27°C day/night) at seedling stage or from anthesis to maturity decreased average leaf photosynthetic rate of wheat by 32 % and 11%, respectively. Heat stress decreases plant photosynthetic capacity, limiting metabolism and chloroplasts oxidative damage with reduced dry matter accumulation and grain yield (Filaček *et al.,* 2022). According to Mahdavi *et al.* (2021) reduction in photosynthesis under stress conditions is an attribute of both stomatal and non stomatal. Photosynthetic rate decline under stress condition and extent of decline depend upon cultivar and development stage (Alghabari *et al.* 2021). Photosynthetic rate decline under late sown condition, heat tolerant genotype maintain optimum photosynthetic rate at grain filling stages (Gupta *et al.,* 2015; Nagar *et al.,* 2017). The present results also (Table 4.11) indicated a reduction in photosynthetic rate under LS and VLS as compared to TS conditions. Genotype WH711 shows minimum percentage reduction in photosynthetic rate compared to all other varieties under different sowing conditions.

Stomatal conductance is the physiological parameter which influences yield under heat stress condition. Increased stomatal conductance leads to transpirational cooling and canopy temperature depression (Munjal and Dhanda, 2004). Sabagh *et al.* (2017) reported the positive correlation of stomatal conductance with grain yield, grain numbers per spike, spike yield and spike length. Mahdavi *et al.* (2017) reported higher temperature lead to higher stomatal conductance as compared to ambient condition. Zubaidi *et al.*, (2021) mentioned stomatal conductance as key factor affecting photosynthesis in plants due to speeding up of water passage through pores of plant. This research shows decreasing trend for stomatal conductance. Minimal percent reduction was shown by HD2967 under LS and VLS compared to TS condition.

Transpiration rate is an index of physiological attributes which is strongly affected by climatic variations, by providing a cooling effect to plant canopy. In the present investigation (Table 4.12), transpiration rate was higher under TS conditions as comparatively to LS and VLS condition. The transpiration rate significantly varied among the genotypes and environment. Genotype HD2967 showed minimum percentage reduction under LS and VLS condition compared to other genotypes. Mahdavi *et al.* (2021) and Dvivedi *et al.* (2017) reported that there was a reduction in transpiration rate under heat stress and it was due to the unavailability of enough water caused by lower conductance. Pooja and Munjal (2019) reported reduced transpiration under heat stress condition. High rate of transpiration in tolerant genotypes showed similar trends with the results of this attribute in the present study. It was inferred that enhanced transpiration might help tolerant genotype in maintaining higher rate of photosynthesis through cooling effect.

Chlorophyll content is important traits that prevents photo inhibition and hence decrease carbohydrate losses for grain development in genotypes exposed to heat stress (Ananthi *et al.*, 2013). Madhan *et al.* (2000) confirms that stability of chlorophyll under stress is very significant and considered as chlorophyll stability index (CSI). High CSI led to high photosynthesis which helps the crops to survive in stress situations. Heat stress at reproductive stage altered the chlorophyll content due to enhanced senescence activity and high chlorophyll content and stay green character is an indication of heat tolerance. In present study (Table 4.14) reduction in chlorophyll content was observed under LS and VLS condition as compared to TS condition in all genotypes. Chlorophyll content index (CCI) was showing minimal percentage decrease in HD2967 under both VLS and LS conditions. Dhyani *et al.* (2013) reported that heat stress drastically affects chlorophyll content and was higher in tolerant genotypes under late sown conditions in wheat.

Chlorophyll fluorescence can be an excellent tool to study the stress induced plants as it indicate changes in PSII which is believed to play a key role in the response of leaf photosynthesis to environmental stresses (Mahdavi *et al.*, 2021). The Fv/Fm value is the most frequently used parameter as it gives information about structure and function of PSII. Filaček *et al.* (2022) reported that drought tolerant cultivars showed a smaller decrease in photosynthetic efficiency (Fv/Fm). High temperature affect thylakoid related reactions, changing the amount of absorbed light energy that is transduced from photo system II (PSII) to photo system I (PSI) and in turn, altering the pattern of chlorophyll fluorescence (Sheikh *et al.* 2010). The results of present investigation indicated that (Table 4.15) chlorophyll fluorescence show a declining trend from 7 DAA to 14 DAA. Chlorophyll fluorescence was showing minimal percentage decrease in HD2967 under both VLS and LS conditions.

Anthocyanin content can be explained by C/N balance hypothesis as proposed by Nyugen and Nimeyer (2008). Anthocyanins protect the photosynthetic apparatus against photo damage by reducing visible light under conditions when UV-radiation inhibits photosynthesis (Steyn *et al.*, 2002). In present study (Table 4.16) enhancement in anthocyanin content was observed from 7DAA to 14 DAA in all genotypes. Anthocyanin was showing minimal percentage decrease in HD2967 under both VLS and LS conditions.

Uptake of essential mineral nutrients (root, stem and leaf) plays a significant role in ameliorating the stress conditions especially the heat stress. Nitrogen is a primary nutrient in wheat and is a major constituent of chlorophyll which is the most essential pigment needed for photosynthesis and amino acids in plants (Tairo and Ndakidemi, 2013). In present study, all the genotypes exhibit a significant reduction in the uptake of the nitrogen, phosphorus and potassium under heat stress (Table 4.8 to 4.10). Nutrients reach to the surface of root by mass flow and diffusion processes. Mass flow and diffusion processes are positively correlated to moisture content of the soil. Movement of nutrients *via* plant is also associated with soil water content (Khaton *et al.*, 2016). Thus, the greater content and uptake of N, P and K is observed in TS compared to VLS and LS. In root, stem and leaves minimum percentage reduction was observed in HD2967 for nitrogen uptake in all sowing conditions. Whereas, for P content minimum reduction percentage was observed in WH1021 in roots, HD2967 in stem and WH1021 in leaves. Potassium content was found to reduce minimum in HD2967 in roots and leaves and WH1021 in stem under all conditions.

5.2 Growth parameters in response to high temperature condition

Temperature higher than the optimum generally shortens the crop duration. The raised temperature cause early maturity as it hastens the growth and development of the crop. Ehdaie *et al.* (2008) observed that there is a strong positive correlation between dry matter of different plant parts with the yield. In the present study, fresh and dry weight of leaf, stem and root were reduced under LS and VLS condition as compared to TS condition in all genotypes at all growth stages (Table 4.2 to 4.7). Begum and Neesa (2014) observed that the minimal reduction in stem dry weight (2.87) was observed in at harvest under timely sown condition. The effect of high temperature together significantly reduces shoot and root dry weights (Suliman *et al.*, 2021). Similarly, heat stress produces substantial decreases in leaf area and dry matter accumulation in roots and shoots (Biswas *et al.*, 2019)

5.3 Yield parameters in response to high temperature condition

Number of productive tiller, number of spikelet/spike, spike length (cm), grain weight (g)/spike, number of grains/spike, biomass (g/m^2), grain yield (g) and 1000 grain weight (g) were high in genotypes under TS condition as compare to genotypes under LS and VLS condition as indicated in Table 4.17. The results are corroborated with the results of investigators including Modarresi *et al.*, 2010; Islam *et al.*, 2017; Irfan *et al.*, 2018; Jaiswal *et al.*, 2018. According to Rehman *et al.* (2021) high temperature stress during reproductive stage has detrimental effect on 1000- grain weight, spike length and number of grains/spike. Temperature stress induced reduction was found greater in LS and VLS condition than TS for yield parameters. Heat stress treatment significantly reduced grain number per panicle, 1000 grain weight (g), grain weight per panicle (g) and grain yield (g) by 18 %, 13 %, 25 % and 29 % for first variety and by 26%, 15%, 32% and 37 % for second variety, respectively compared to normal condition (Jing *et al.*, 2020). Reduced no. of tillers, grain yield per plant and test weight for different wheat lines were reported by Dubey *et al.* (2019); high reduction in tiller number (51.2 %), spike length (39.9 %) and grain yield (60.3 %) reported by Dwivedi *et al.* (2017); elevated temperature caused a reduction in grain yield reported by Singh *et al.* (2017). Kaur *et al.* (2021) found that biomass and grain yield were significantly higher in all the genotypes under timely sown condition as compared to late sown condition. Ahmad *et al.* (2021) reported the highly significant effect of sowing date, cultivars and their interaction on grain yield. In general, reduction in mean grain yield of wheat genotypes was 65 %, observed under stressed condition as compared to optimum planting environment. Sharma *et al.* (2021) showed reduction in 1000-grain weight and grain number/spike in wheat accessions under high-temperature conditions. A significant linear reduction was observed for 1000-grain weight of wheat genotypes with delayed sowing. 1000-grain weight was drastically decreased with late sowing (Alghabari *et al.*, 2021). A significant decrease was recorded for biological weight at late sowing. Grain yield of wheat genotypes was significantly increased at early sowing and decreased with delay in sowing time. The observed yield reductions were attributed to the negative effects of heat stress on the various morpho-physiological characters of the crop, which have been well documented by, Tiwari *et al.* (2017), Bala and Sikder (2018), Sangwan *et al.* (2018), Moshatati *et al.* (2019), Hussain *et al.* (2019), Dubey *et al.* (2020) and several others. Spike length was significantly reduced at late sowing. Number of grains/spike significantly decreased with late sowing (Poudel *et al.* 2020). The effects of sowing date and high temperature on 1000-grain weight, biomass per plant, grain yield per plant, grains per spike, spike length, spikelet per spike and tillers per plant, has also been reported by Khan *et al.* (2020).

Heat susceptibility index (HSI) is a useful criterion to select heat tolerant genotypes. The genotypes with high positive HSI are susceptible to higher temperature and genotypes with low HSI are tolerant to high temperature (Fischer and Maurer, 1978). Based on HSI value, Bakshi *et al.* (2020) classified wheat genotypes as highly heat tolerant (HSI <0.50); heat tolerant (HSI <0.51-0.75); moderately heat tolerant (HSI < 0.761.00) and heat susceptible (HSI >1.00). In present investigation (Table 4.18) minimum HSI was found in WH1105 in VLS condition and maximum HSI was found in WH711 in VLS condition compared to other varieties in different growing conditions. HSI has also been used by Suresh *et al.* (2018), Meena *et al.* (2019), Sareen *et al.* (2020), Shehrawat *et al.* (2020) and Ahmad *et al.* (2021) for evaluation of wheat genotypes for heat tolerance

CHAPTER-VI

SUMMARY AND CONCLUSION

The present investigation was conducted in six wheat genotypes grown under timely (TS), late sown (LS) and very late sown (VLS) conditions to study the photosynthetic efficiency and nutrient uptake and other physiological traits to find a correlation between photosynthesis and nutrient content. Six wheat genotypes, namely WH147, WH711, WH1105, WH1184, WH1021 and HD2967 were grown under TS, LS and VLS in the screen house of the Department of Botany and Plant Physiology. Results showed that various growth, physiological, yield and its attributes got adversely affected under late and very late sown conditions and are summarized as below: -

1. Canopy temperature was measured at 45, 75, and 105 DAS in all genotypes under all environmental conditions. A higher canopy temperature was observed under LS and VLS conditions as compared to timely sown conditions. Wheat genotype, WH711 maintained minimum mean CT at 45, while HD2967 at 75 DAS and WH1021 at 105 DAS showed minimum CT as compared to all genotypes. However, there was no significant variation in the value of CT.
2. FW and DW of leaves, stem and roots decreased under LS and VLS conditions at 45, 75 and 105 DAS. Wheat genotype HD2967 sustained higher DW of all plant parts followed by WH 1021 under LS and VLS conditions. However, WH 147 showed minimum FW and DW of stem, root and leaves under LS and VLS conditions.
3. Chlorophyll content (SPAD values) was reduced with late sown conditions in all genotypes. However maximum values were observed in HD2967 followed by WH1021 at 7 and 14 DAA under TS, LS and VLS conditions. However minimum chlorophyll content (SPAD values) was observed in genotype WH711 at 7 DAA and WH147 at 14 DAA under TS, LS and VLS conditions. Chlorophyll fluorescence was also reduced with late sown conditions in all genotypes with maximum values in HD2967 at 7 and 14 DAA under TS, LS and VLS conditions.
4. Photosynthetic rate, stomatal conductance, and transpiration rate decreased under LS and VLS conditions in all genotypes. However maximum mean values were observed in WH1021 followed by HD2967 at 7DAA and 14 DAA under TS, LS and VLS conditions. WH147 was recorded for a minimum photosynthetic rate as compared to other genotypes.
5. N, P, K content of stem, root and leaves decreased under LS and VLS conditions as compared to TS conditions. Leaves showed a higher amount of N content as compared to stem and root in all genotypes and maintained maximum values in the HD2967

genotype. Phosphorus content was found higher in the stem as compared to leaves and roots in all genotypes and a similar trend was observed for K content in different plant parts. Wheat variety HD2967 showed maximum N, P, and K content followed by WH 1021 under TS, LS and VLS conditions.

6. Heading was found earliest in genotypes WH1184 under TS, LS and VLS conditions. However, the late heading was found in genotypes WH1021 and WH147 respectively under TS, LS and VLS conditions.
7. Anthesis was found earliest in genotypes WH1184 under TS, LS and VLS conditions. However, the maximum number of days to anthesis was found in genotypes WH1021 under TS and WH147 under LS and VLS conditions.
8. The earliest days to maturity was found in genotypes WH1184, however, late maturity was found in genotypes WH1021 followed by HD 2967 under LS and VLS condition.
9. Plant height was found maximum in WH1021 followed by WH147 and HD2967 under TS, LS and VLS conditions. Spike length was also reported highest in HD2967 with maximum no. of spikelets/spike and no. of grains/spike under LS and VLS conditions.
10. Plant biomass was maximum (mean values) in HD2967 followed by WH711 and WH1021. However mean grain yield/plant was reported maximum in HD2967 followed by WH1021, WH1184, WH1105, WH711 and WH147. Similar results were observed for 1000 grain weight under LS and VLS conditions.

Conclusion:

The environmental condition affects the growth and yield of wheat genotypes under late and very late sown conditions. HD2967 and WH1021 maintained higher photosynthesis rates with higher NPK content in different plant parts. Wheat genotype HD2967 followed by WH1021 evaluated as heat tolerant based on minimal reduction in growth, physiological traits, yield and its attributes under LS and VLS as compared to TS conditions.

BIBLIOGRAPHY

.Agarwal, V. P., Gupta, N. K., Gupta, S. and Singh, G. (2021). Screening of wheat germplasm for terminal heat tolerance under hyper-arid conditions. *Cereal Research Communications*, 1-9.

Ahmed, M. and Farooq, S. (2013) Growth and physiological responses of wheat cultivars under various high temperatures: possible mediation by abscisic acid. *Australian Journal of Plant Physiology,* **9:** 529-537

Ahmed, M., Hassan, F.U. and Asif, M. (2012). Physiological response of bread wheat (*Triticum aestivum* L.*)* to high temperature and moisture stresses. *Australian Journal of Crop Science*, **6**(4): 749.

Akter, N., and Rafiqul Islam, M. (2017). Heat stress effects and management in wheat. A review. *Agronomy for sustainable development,* **37**(5): 1-17

Al Khatib, K., and Paulsen, G. M. (1990). Photosynthesis and productivity during high temperature stress of wheat genotypes from major world regions. *Crop Science*, **30**(5): 1127-1132.

Alam, M. P., Kumar, S., Ali, N., Manjhi, R. P., Kumari, N., Lakra, R. K., and Izhar, T. (2013). Performance of wheat varieties under different sowing dates in Jharkhand. *Journal of Wheat Research, 5*(2): 61-64.

Alexander, L. V., X. Zhang, T. C. Peterson, J. Caesar, B. Gleason, A. M. G. Klein, T. M. Haylock, D. Collins, B. Trewin, F.Rahimzadeh, A. Tagipour, P. Ambenje, K. Rupa Kumar, J.Revadekar, and G. Griffiths, (2006): Global observed changes in daily climate extremes of temperature and precipitation .*Journal of Geophysical Research: Atmospheres* **111**: 1–22.

Alghabari, F., Shah, Z. H., Elfeel, A. A., and Alyami, J. H. (2021). Biochemical and physiological responses of thermostable wheat genotypes for agronomic yield under heat stress during reproductive stages. *Agronomy*, **11**(10):2080.

Ali, M. A., Hussain, M., Khan, M. I., Ali, Z., Zulkiffal, M., Anwar, J., Sabir, W. and Zeeshan, M. (2010). Source-sink relationship between photosynthetic organs and grain yield attributes during grain filling stage in spring wheat (*Triticum aestivum L.*). *Integrated Journal of Agriculture and Biology*, **12**(4): 509-515.

Anjum, F., Wahid, A., Javed, F. and Arshad, M. (2008). Influence of foliar applied thiourea on flag leaf gas exchange and yield parameters of bread wheat (*Triticum aestivum* L.) cultivars under salinity and heat stress. *Internatıonal Journal of Agrıculture and Bıology*, **10**: 619-626.

Anonymous, 2010. Food outlook, global market analysis, (GIEWS), Global information and early warning system food and agriculture: **2**

Antelmo, R.F., Silva Cassel, D., Ariano, M.M.J., Antanio, C.O. and Marcos, A.B. (2010) Chlorophyll fluorescence in rice: probing of senescence driven changes of PSII activity on rice varieties differing in grain yield capacity. *Brazilian Journal of Plant Physiology*, **22**: 35-41.

Araus, J. L., G. A. Slafer, M. P. Reynolds, and C. Royo, (2002): Plant breeding and drought in C_3 cereals: what should we breed for? *Annuals of Botany*. **89**: 925–940**.**

Arfan, M., Athar, H. R. and Ashraf, M. (2007). Does the exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress? *Journal of Plant Physiology*, **164**(6): 685-694.

Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., Kimball, B. A., Ottman, M. J., Wall, G. W., White, J. W., Reynolds, M. P., Alderman, P. D., Prasad, P. V. V., Aggarwal, P. K., Anothai, J., Basso, B., Biernath, C., Challinor, A. J., De Sanctis, G., Doltra, J., Fereres, E., Garcia-

Vila, M., Gayler, S., Hoogenboom, G., Hunt, L. A., Izaurralde, R. C., Jabloun, M., Jones, C. D., Kersebaum, K. C., Koehler, A-K., Müller, C., Kumar, S. N., Nendel, C., O'Leary, G., Olesen, J. E., Palosuo, Priesack, T. E., Rezaei, E. E., Ruane, A. C., Semenov, M. A., Shcherbak, I., Stockle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Thorburn, P. J., Waha, K., Wang, E., Wallach, D., Wolf, J., Zhao, Z. and Zhu, Y. (2015). Rising temperatures reduce global wheat production. *Nature Climate Change*, **5**(2): 143-147.

Asseng, S., Foster, I. A. N., and Turner, N. C. (2011). The impact of temperature variability on wheat yields. *Global Change Biology*, **17**(2): 997-1012.

Ayeneh, A., Van Ginkel, M., Reynolds, M. P. and Ammar, K. (2002). Comparison of leaf, spike, peduncle and canopy temperature depression in wheat under heat stress. *Field Crops Research*, **79**(2-3): 173-184

Bahar, B., Yildirim, M. and Barutçular, C. (2009) Relationships between stomatal conductance and yield components in spring durum wheat under Mediterranean conditions. *Notulae Botanicae HortiAgrobotanici Cluj-Napoca*, **37**: 45-48

Bala, S., Asthir, B. and Bains, S.N. (2014). Effect of terminal heat stress on yield and yield attributes of wheat. *Indian Journal of Applied Research*, **4**: 1-2.

Balla, K., Kasari, L., Bencze, S., Kiss, T. and Veisz, O. (2012) Study of yield components under heat stress conditions in wheat. *Tagung der vereinigung der pflanzenzuchter and saatgutkaufleute osterreichs*, **63**: 99-101.

Begum, F. and Nessa, A. (2014). Effects of temperature on some physiological traits of wheat. *Journal of Bangladesh Academy of Sciences*, **38**(2): 103-110

Belay, G. A., Zhang, Z. and Xu, P. (2021). Physio-morphological and biochemical trait-based evaluation of Ethiopian and Chinese wheat Germplasm for drought tolerance at the seedling stage. *Sustainability*, **13**(9): 4605.

Bhanu, A. N., Arun, B., and Mishra, V. K. (2018). Genetic variability, heritability and correlation study of physiological and yield traits in relation to heat tolerance in wheat (Triticum aestivum L.). *Biomedical Journal of Scientific and Technical Research*, **2**(1): 2112-2116.

Bhardwaj, R., Sharma, A., Singh, A., Sharma, Singh, H. and Sharma, B.K. (2017). Determination of heat susceptibility indices for some quantitative traits in bread wheat (*Triticum aestivum* L.).*International Journal of Pure Applied Bioscience*, **5** (2): 230-239.

Bhusal, N., Sarial, A. K., Sharma, P. and Sareen, S. (2017). Mapping QTLs for grain yield components in wheat under heat stress. *PLoS One*, **12**(12): e0189594.

Biswas, D., Ma, B., and Morrison, M.J. 2019. Changes in leaf nitrogen and phosphorus content, photosynthesis, respiration, growth, and resource use efficiency of a rapeseed cultivar as affected by drought and high temperatures. *Canadian Journal of Plant Science* **99**(4): 488-498.

Blum, A., Klueva, N. and Nguyen, H.T. (2001) Wheat cellular thermo-tolerance is related to yield under heat stress. *Euphytica*, **117**: 117-123.

Bravo-F, P.; Uribe, E.G2018. Temperature dependence of the concentration kinetics of absorption of phosphate and potassium in corn roots. *Plant Physiology*, **67**: 815–819.

Chatrath, R., Mishra, B., Ortiz Ferrara, G., Singh, S.K. and Joshi, A.K. (2007). Challenges to wheat production in South Asia, *Euphytica*, **157**: 447–456.

Chaudhary, S. (2004). Evaluation of wheat genotypes at different dates of sowing under irrigated conditions. Thesis, M.Sc. Ag. (Agronomy), G.B. Pant University of Agriculture and Technology, Pantnagar

Chopra, R.K. (2018) Effects of temperature on the in vivo assay of nitrate reductase in some C3 and C4 Species. *Annuals of Botany*, **51**, 617–620.

Choudhary, R. C., Sharma, N. K., Kumar, M. and Kumar, R. (2015). Wheat genotypes (*Triticum aestivum* L.) vary widely in their responses of fertility traits to high temperature at anthesis. *International Research Journal of Biological Sciences,* **3**(7): 54-60.

Cossani, C. M., and Reynolds, M. P. (2012). Physiological traits for improving heat tolerance in wheat. *Plant Physiology,* **160**(4): 1710-1718.

Cui, L.; Cao, R.; Li, J.; Zhang, L.; Wang, J. (2016). High temperature effects on ammonia assimilation in leaves of two *Festuca arundinacea* cultivars with different heat susceptibility. *Plant Growth and Regulation*. **49**: 127–136.

Curtis, B. C., Rajaram, S. and Macpherson, H.G. (2002). Bread wheat: Improvement and Production. *FAO Plant Production and Protection Series,* **30**: 12-15.

Dabre, W. M., Lall, S. B., and Ingole, G. L. (1993). Effects of sowing dates on yield, ear number, stomatal frequency and stomatal index in wheat. *Journal-Maharashtra agricultural universities*, **18**: 64-64.

Dash, S. and Mohanty, N. (2001) Evaluation of assays for the analysis of thermo-tolerance and recovery potentials of seedlings of wheat (*Triticum aestivum* L.) cultivars. *Journal of Plant Physiology*, **158**: 1153-1165.

De Costa WAJM (2011). A review of the possible impacts of climate change on forests in the humid tropics. *Journal of the National Science Foundation of Sri Lanka.***39**: 281-302

Deshmukh, R., Tomar, N. S., Tripathi, N., and Tiwari, S. (2012). Identification of RAPD and ISSR markers for drought tolerance in wheat (*Triticum aestivum* L.). *Physiology and Molecular Biology of Plants*, **18**(1): 101-104.

Dhyani, K., Ansari, M. W., Rao, Y. R., Verma, R. S., Shukla, A. and Tuteja, N. (2013). Comparative physiological response of wheat genotypes under terminal heat stress. *Plant Signaling and Behavior*, **8**(6): 245-264

Dias, A.S., Bagulho, A.S., and Lidon, F.C. (2008) Ultrastructure and biochemical 870 traits of bread and characters of four wheat genotypes under heat stress. *International Journal of Botany*, **1**(2): 124-127

Dias, A.S., Semedo, S.J., Ramalho, J.C. and Lidon, F.C. (2010). Bread and durum wheat under heat stress: a comparative study on the photosynthetic performance. *Journal of Agronomy and Crop Science*, **197**: 50–56.

Dias, M.O.S., Cunha, M.P., Jesus, C.D.F., Rocha, G.J.M., Geraldo, J., Pradella, C., Rossell, C.E.V., Maciel, R. and Bonomi, A. (2011). Second generation ethanol in Brazil: can it compete with electricity production. *Bioresource Technology,* **102**: 8964–8971.

Djanaguiraman, M. and Prasad, P. V. (2010). Ethylene production under high temperature stress causes premature leaf senescence in soybean. *Functional Plant Biology*, **37**(11): 1071-1084.

Dodd, I.C. (2003). Hormonal interactions and stomatal responses. *Journal of Plant Growth Regulation*, **22**: 32-46.

Dwivedi, R., Prasad, S., Jaiswal, B., Kumar, A. and Tiwari, A. (2017). Evaluation of wheat genotypes (*Triticum aestivum* L.) at Grain Filling Stage for heat tolerance. *International Journal of Pure and Applied Bioscience,* **5**: 971–975.

Eldey, E., El Naim, A., Abdelrahman, M. K., and Ishag, A. A. (2018). Effect of sowing dates and cultivars on seed yield of wheat (Triticum Aestivum L.) in New Halfa Eastern Sudan. *International Journal* *of Research Studies in Agricultural Sciences,**4***(11): 34-39.

Elmetwalli, A. M. H., Tyler, A. N., Hunter, P. D., and Salt, C. A. (2012). Detecting and distinguishing moisture-and salinity-induced stress in wheat and maize through in situ spectroradiometry measurements. Remote Sensing Letters, **3**(4): 363-372.

FAO (2021). Food security and nutrition around the world: hunger is on the rise. Rome.

Farooq, M., Bramley, H., Palta, J. A., and Siddique, K. H. (2011). Heat stress in wheat during reproductive and grain-filling phases. *Critical Reviews in Plant Sciences,* **30**(6): 491-507

Feldman, M. (2001). The origin of Cultivated Wheat, Lavosier Publishing, Paris

Feldman, M., and Kislev, M. E. (2007). Domestication of emmer wheat and evolution of free-threshing tetraploid wheat. *Israel Journal of Plant Sciences*, **55**(3-4): 207-221.

Feng, B., Liu, P., Li, G., Dong, S. T., Wang, F. H., Kong, L. A., and Zhang, J. W. (2014). Effect of heat stress on the photosynthetic characteristics in flag leaves at the grain filling stage of different heat-resistant winter wheat varieties. *Journal of Agronomy and Crop Science,* **200**(2): 143-155

Filaček, A., Živčák, M., Ferroni, L., Barboričová, M., Gašparovič, K., Yang, X., and Brestič, M. (2022). Pre-Acclimation to Elevated Temperature Stabilizes the Activity of Photosystem I in Wheat Plants Exposed to an Episode of Severe Heat Stress. *Plants*, 11(5): 616.

Fischer, R. A. (1985). Physiological limitation to producing wheat in semi-tropical and tropical environments and possible criteria. In: R. C. Villareal and A. R. Klatt (Eds.), *Wheats for more tropical environments* 209-230. CIMMYT, Maxico, D. F.

Fischer, R.A. and Maurer, R (1976) Crop temperature modification and yield potential in a dwarf spring wheat. *Crop Science*, **16**: 855-859.

Gabaldon-Leal, C. Webber, H. Otegui, M. E. Slafer, G. A. Ordonez, R. A. Gaiser, T. and Ewert, F. (2016). Modelling the impact of heat stress on maize yield formation. *Field Crops Research*, **198:** 226-237.

Gautam, A., Sai Prasad, S. V., Jajoo, A., and Ambati, D. (2015). Canopy temperature as a selection parameter for grain yield and its components in durum wheat under terminal heat stress in late sown conditions. *Agricultural research*, **4**(3): 238-244.

Gautam, R.K., Mudhoo, A., Lofrano, G. and Chattopadhyaya, M.C (2014) Biomass derived biosorbents for metal ions sequestration: adsorbent modification and activation methods and adsorbent regeneration. *Journal of Environmental Chemical Engineering*, **2(1):** 239–259.

Gibson, L.R. and Paulsen, G.M. (1999). Yield components of wheat grown under high temperature stress during reproductive growth. *Crop Science,* **39**(6): 1841–1846.

Giri, A., Heckathorn, S., Mishra, S., and Krause, C. (2017). Heat stress decreases levels of nutrient-uptake and-assimilation proteins in tomato roots. *Plants***,** ***6***(1): 6.

Giunta, F., Motzo, R. and Pruneddu, G. (2008) Long-term selection for yield in durum wheat also induced changes in leaf and canopy traits. *Field Crops Research*, **106**: 68–76.

Gupta, M., Chawla, V., Dhanda, S.S., Saharan, R.P. and Munjal, R. (2015) Effect of terminal heat stress on yield and yield components of bread wheat genotypes. *Research on Crops,* **16**: 42–52.

Gutierrez, M., Reynolds, M.P., Raun, W.R., Stone, M.L. and Klatt, A.R. (2010) Spectral water indices for assessing yield in elite bread wheat genotypes under well-irrigated, water-stressed and high-temperature conditions. *Crop Science,* **50**: 197-214.

Hakim, M.A., Hossain, A., Jaime, A., Silva, T.D., Zvolinsky, V.P. and Khan, M.M. (2012) Yield, protein and starch content of twenty wheat (*Triticum aestivum* L.) genotypes exposed to high temperature under late sowing conditions. *Journal of Scientific Research*, **4**: 477-89.

Hamam, K.A. (2013) Estimation of genetic parameters using five populations model in three bread wheat crosses under normal irrigation and drought stress. 8th International Plant Breeding. International Conference, Kafr El Sheikh University, Egypt, 14th -15th May 2013.

Hasanuzzaman, M., Nahar, K., Alam, M., Roychowdhury, R. and Fujita, M. (2013). Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *International journal of molecular sciences*, **14** (5): 9643-9684.

Hays, D. B., J. H. Do, R. E. Mason, G. Morgan, and S. A.Finlayson, 2007: Heat stress induced ethylene production in developing wheat grains induces kernel abortion and increased maturation in a susceptible cultivar. *Plant Sciences.* **172**:1113–1123.

Hays, D., Mason, E., Do, J. H., Menz, M., and Reynolds, M. (2007). Expression quantitative trait loci mapping heat tolerance during reproductive development in wheat (Triticum aestivum). In Wheat production in stressed environments Springer, Dordrecht. 373-382

Heckathorn S.A., Giri A., Mishra S., Bista D 2014.. Heat stress and roots. . Climate Change and Plant Abiotic Stress Tolerance. Wiley Blackwell; Weinheim, Germany: 109–136.

Heimler, D. Romani, A. and Ieri, F. (2017). Plant polyphenol content, soil fertilization and agricultural management: A review. *European Food Research and Technology*, **243**(7): 1107-1115.

Hennessy, K., R. Fawcett, D. Kirono, F. Mpelasoka, D. Jones, J.Bathols, P. Whetton, M. Stafford Smith, M. Howden, C.Mitchell, and N. Plummer, 2008: An Assessment of the Impact of Climate Change on the Nature and Frequency of Exceptional Climatic Events. CSIRO and Bureau of Meteorology.http://www.daff.gov.au/data/assets/pdf file/0007/721285/csirobom-report-future-droughts.pdf

Hilbert, G. Soyer, J. P. Molot, C. Giraudon, J. and Milin, S. (2003). Effects of nitrogen supply on must quality and anthocyanin accumulation in berries of cv. Merlot. *Vitis*, **42**(2): 69-76.

Hoagland, D.R., and Arnon, D.I. (1950). The water - culture method for growing plants without soil. California Agricultural Experiment Station circular, Berkeley, California, *347:* 1–32

Hungria, M. and Kaschuk, G. (2014) Regulation of N2 fixation and NO3 −/NH4 + assimilation in nodulated and N-fertilized Phaseolus vulgaris L. exposed to high temperature stress. *Environmental and . Experimental. Botany*, **98**: 32–39.

Irfan, M. and Imran, A. (2018). The effect of heat stress on morpho physiological traits of *Triticum aestivum* l. Genotypes, (13-23).

Irfaq, M., Muhammad, T., Amin, M. and Jabbar, A. (2005) Performance of yield and other agronomic planting windows. *Journal of Animal and Plant Sciences*, **23**: 1407–1414.

Ishag, H. M. (1994). Genotype Differences in Heat Stress in Wheat in the Irrigated Gezira Scheme. In Wheat in Heat-stressed Environments: Irrigated, Dry Areas, and Rice-wheat Farming Systems: Proceedings of the International Conferences: Wheat in Hot, Dry, Irrigated Environments, Wad Medani, Sudan, 1-4 February 1993, Wheat in Warm Area, Rice-wheat Farming Systems, Dinajpur, Bangladesh, **2161**: 170. CIMMYT.

Islam, M. R., Haque, K. S., Akter, N. and Karim, M. A. (2014). Leaf chlorophyll dynamics in wheat based on SPAD meter reading and its relationship with grain yield. *Journal of Scientia Agriculture*, **8**(1): 13-18.

Islam, M.T., Mamun, M.A.A., Matin, M.A. and Jahiruddin, M.. (2011) Effects of tillage and irrigation on the growth and yield of wheat. *Journal of agroforestry and environment*, **5**: 95-98

Jaiswal, S. K., Prakash, R., Skalny, A. V., Skalnaya, M. G., Grabeklis, A. R., Skalnaya, A. A., ... and Prakash, N. T. (2018). Synergistic effect of Selenium and UV-B radiation in enhancing antioxidant level of wheatgrass grown from Selenium rich wheat. *Journal of Food Biochemistry*, **42(5)**: 12577

Jalota, S.K., G.B.S. Singh, S.S. Chahal, S. Ray, P. Bhupinder-Singh and K.B. Singh, (2010). Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize–wheat cropping system: Field and simulation study. *Agricultural Water Management*, **97**(1): 83- 90

Jangid, K.K. and Srivastava, P.J. (2018). Canopy Temperature Depression and Stay Green: Major components for identifying terminal heat stress resistant genotypes of wheat. *International Journal of Applied Bioscience*, **6**(3): 374-381.

Jhanji, S. and Sekhon, N. K. (2018). Evaluation of potential of portable chlorophyll meter to quantify chlorophyll and nitrogen contents in leaves of wheat under different field conditions. *Journal of Experimental Botany*, **56**(10): 750-758

Joshi AK, B Mishra, R Chatrath, GO Ferrara and RP Singh. 2007. Wheat improvement in India: Present status, emerging challenges and future prospects. *Euphytica*. **157**: 431-446.

Kant, S., Lamba, R. A. S., Arya, R. K. and Panwar, I. S. (2014). Effect of terminal heat stress on stability of yield and quality parameters in bread wheat in south-west Haryana. *Journal of Wheat Research*, **6**(1).

Karimizadeh, R., and Mohammadi, M. (2011). Association of canopy temperature depression with yield of durum wheat genotypes under supplementary irrigated and rainfed conditions. *Australian Journal of Crop Science*, **5**(2): 138-146.

Karmakar, S. and Shrestha, M.L. (2000). Recent climatic changes in Bangladesh. SMRC No. 4. SAARC Meteorological Research Centre, Dhaka.

Kaur, J., Sandhu, S. S., and Sharma, S. (2021). Yield response of wheat grown under periodic heat stress imposed by using mini heat tents. *Journal of Agronomy and Crop Science,* **207**(2), 285-303.

Kavita, Munjal, R., Dhanda, S.S., Kumar, N. and Sunita, (2015) Association of morpho-physiological traits in different wheat species under heat stress condition. *International Journal of Tropical Agriculture*, **33**, *3901-3905.*

Khan, I., Raza, M. A., Awan, S. A., Shah, G. A., Rizwan, M., Ali, B., and Huang, L. (2020). Amelioration of salt induced toxicity in pearl millet by seed priming with silver nanoparticles (AgNPs): The oxidative damage, antioxidant enzymes and ions uptake are major determinants of salt tolerant capacity. *Plant Physiology and Biochemistry*, ***156***: 221-232.

Khan, M.A.U. and F. Mohammad. 2018. Effect of genotype × environment interaction on grain yield determinants in bread wheat. *Sarhad Journal of Agriculture,* **34**: 54-62.

Khan, S. U., Din, J. U., Qayyum, A., Jaan, N. E. and Jenks, M. A. (2015). Heat tolerance indicators in Pakistani wheat (*Triticum aestivum* L.) genotypes. *Acta Botanica Croatica*, **74**(1): 109-121.

Khlestkina, E. (2013). The adaptive role of flavonoids: emphasis on cereals. *Cereal Research Communications*, **41**(2): 185-198

Kirpa Ram., Munjal, R., Sunita., Pooja. and 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 and Biotechnology*, **6(3)**, 528 – 537.

Koc, M., Barutçular, C. and Tiryakioglu, M. (2008) Possible heat-tolerant cultivar improvement through the use of flag leaf gas exchange traits in a Mediterranean Environment. *Journal of the Science of Food and Agriculture*, **88**: 1638-1647.

Koenig, R. and Johnson, C. (1942) Colorimetric Determination of Phosphorus in Biological Materials. *Industrial and Engineering Chemistry Analytical Edition*, 14**(2)**: 155–156.

Krupnik T J, Ahmed Z U, Timsina J, Shahjahan M, Kurishi A S M A, Miah A A, Rahman B M S, Gathala M K and McDonald A.J. (2015). Forgoing the fallow in Bangladesh‟s stress-prone coastal deltaic environments: Effect of sowing date, nitrogen, and variety on wheat yield in farmer's fields. *Field Crops Res***170**: 7-20.

Kumar, N., Prasad, S., Dwivedi, R., Kumar, A., Yadav, R.K., Singh, M.P. and Yadav, S.S. (2016). Impact of Heat Stress on Yield and Yield Attributing Traits in Wheat (*Triticum aestivum* L.) lines during grain growth development. *International Journal of Pure and Applied Bioscience*, **4**: 179–184

Kumar, P., Singh, F., Kumar, R., Hussain, M. F. and Singh, A. P. (2014). Effect of temperature on performance of wheat varieties under semi-arid conditions of Uttar Pradesh. *International Journal of Plant Research*, **3**(5): 551-552.

Leff, B., Ramankutty, N., and Foley, J. A. (2004). Geographic distribution of major crops across the world. Global biogeochemical cycles**, 18**(1).

Levitt J. 1980. Radiation stress. Response of plant to environmental stresses. Academic Press, New York, NY: 283–344.

Lin, C. W., Fu, S. F., Liu, Y. J., Chen, C. C., Chang, C. H., Yang, Y. W., and Huang, H. J. (2019). Analysis of ambient temperature-responsive transcriptome in shoot apical meristem of heat-tolerant and heat-sensitive broccoli inbred lines during floral head formation. *BMC plant biology*, **19(**1): 1-16.

Lindner, R.C. (1994) Rapid analytical methods for some of the more common inorganic constitutes of plant tissue. *Journal of Plant Physiology*, **19**: 76-86.

Liu, B., Asseng, S., Wang, A., Wang, S., Tang, L., Cao, W., Zhu, Y. and Liu, L. (2017). Modelling the effects of post-heading heat stress on biomass growth of winter wheat. *Agricultural and Forest Meteorology*, **247**: 476-490.

Lyu, Y. Porat, R. Yermiyahu, U. Heler, Y. Holland, D. and Dag, A. (2020). Effects of nitrogen fertilization on pomegranate fruit, aril and juice quality. *Journal of the Science of Food and Agriculture*, **100** (4): 1678-1686

Mahdavi, S., Arzani, A., Maibody, S. A., and Mehrabi, A. A. (2021). Photosynthetic and yield performance of wheat (Triticum aestivum L.) under sowing in hot environment. *Acta Physiologiae Plantarum*, **43**(7): 1-11.

Mahla, R., Madan, S., Kaur, V., Munjal, R., Behl, R. K., and Midathala, R. (2017). Activities of sucrose to starch metabolizing enzymes during grain filling in late sown wheat under water stress. *Journal of Applied and Natural Science*, **9**(1): 338-343.

Mainali K.P., Heckathorn S.A., Wang D., Weintraub M.N., Frantz J.M., Hamilton E.W., . 2014 III Impact of a short-term heat event on C and N relations in shoots vs. roots of the stress-tolerant C_4 grass, *Andropogon gerardii. Journal of Plant Physiology.* **171**: 977–985. doi: 10.1016/j.jplph.2014.04.006.

Mathur, S., and Jajoo, A. (2014). Effects of heat stress on growth and crop yield of wheat (Triticum aestivum). In Physiological mechanisms and adaptation strategies in plants under changing environment Springer, New York, NY. 163-191

Mbarki, S. Sytar, O. Zivcak, M. Abdelly, C. Cerda, A. and Brestic, M. (2018). Anthocyanins of Coloured wheat germplasm in specific response to SaltStress. *Molecules*, **23**(7): 1518.

Michaletz, S. T. Weiser, M. D. McDowell, N. G. Zhou, J. Kaspari, M. Helliker, B. R. and Enquist, B. J. (2016). The energetic and carbon economic origins of leaf thermoregulation. *Nature Plants*, **2**(9): 1-9

Miransari, M., and Smith, D. (2019). Sustainable wheat (Triticum aestivum L.) production in saline fields: a review. *Critical reviews in biotechnology*, **39**(8): 999-1014.

Mishra, D., Shekhar, S., Agrawal, L., Chakraborty, S. and Chakraborty, N. (2017) Cultivar-specific high temperature stress responses in bread wheat (*Triticum aestivum* L.) associated with physicochemical traits and defense pathways. *Food Chemistry*, **221**, 1077–1087.

Mishra, N. P., Mishra, R. K., and Singhal, G. S. (1993). Changes in the activities of anti-oxidant enzymes during exposure of intact wheat leaves to strong visible light at different temperatures in the presence of protein synthesis inhibitors. *Plant physiology*, **102**(3): 903-910.

Mishra, R.K. and Singhal, G.S. (1993) Photosynthetic activity and peroxidation of thylakoid lipids during photoinhibition and high temperature treatment of isolated wheat chloroplasts. *Journal of Plant Physiology*, **141**:286-292.

Misson, L., Limousin, J., Rodriguez, R. and Letts, M. G. (2010) Leaf physiological responses to extreme drought sin Mediterranean Quercus ilex forest. *Plant Cell Environment*, **33:** 1898–1910.

Modarresi, M., V Mohammdi, A Zali and M Mardi, 2010. Response of wheat yield and yield related traits of high temperature. *Cereal Research communications*, **38**(1): 23-31.

Mohammadi, M. (2012a) Effects of kernel weight and source-limitation on wheat grain yield under heat stress. *African Journal of Biotechnology*, **11**: 2931–2937

Mohammadi, M., Karimizadeh, R. and Shefazeadeh, M.K. (2012b) Grain yield performance of bread wheat germplasm under heat and drought field conditions. *Annals of Biological Research*, **3**: 3149-55.

Mohammadi, V., Qannadha, M.R., Zali, A.A. and Yazdi, S.B. (2004) Effect of post anthesis heat stress on head traits of wheat. *International Journal Agriculture Biology*, **6**:42-44.

Mondal, S., Singh, R.P., Mason, E.R., Huerta-Espino, J., Autrique, E. and Joshi, A.K. (2016) Grain yield, adaptation and progress in breeding for early-maturing and heat-tolerant wheat lines in South Asia. *Field Crops Research*, **192**: 78–85.

Munjal, R. and Rana, R.K. (2003) Evaluation of physiological traits in wheat (*Triticum aestivum* L.) for terminal high temperature tolerance. In: Proceedings of the Tenth International Wheat Genetics Symposium, Classical and Molecular Breeding, Poestum, Italy, **2**: 804-805

Munjal, R., and Rana, R. K. (2003). Evaluation of physiological traits in wheat (Triticum aestivum L.) for terminal high temperature tolerance. In Proceedings of the tenth international wheat genetics symposium **2**(3): 804-805.

Munjal, R., Dhanda, S.S., Rana, R.K. and Singh, I. (2004). Membrane thermostability as an indicator of heat toleranceat seedling stage in bread wheat. *National Journal of Plant Improvement*, **6**: 133–135

Nagarajan, S., and Rane, Jagadish (2000). Relationship of seedling traits with drought tolerance in spring wheat cultivars. *Indian Journal of Plant Physiology*, **5**(3): 264-270.

Nahar, K., Ahmad, K. and Fujita, M. (2010). Phenological variation and its relation with yield in several wheat (*Triticum aestivum* L.) cultivars under normal and late sowing mediated heat stress conditions. *Notulae Scientia Biologicae*, **2**(3):51-56.

Nawaz, A., Farooq, M., Cheema, S. A., and Wahid, A. (2013). Differential response of wheat cultivars to terminal heat stress. *International Journal of Agriculture and Biology*, **15**(6).

Nazir A, and Fathi, Ullah (2004).Effect of different seeding rates,sown dates and weed control on grain yield of wheat. *Pakistani Journal of Weed Science and Research*.;**11**(3,4): 19-23.

Nishio, Z., Ito, M., Tabiki, T., Nagasawa, K., Yamauchi, H. andHirota, T. (2013). Influence of higher growing- season temperatures on yield components of winter wheat (*Triticum aestivum* L.). *Crop Science*, **53** (2): 621-628.

Ortiz, R., Sayre, K. D., Govaerts, B., Gupta, R., Subbarao, G. V., Ban, T.O., and Reynolds, M. (2008) Climate change: Can wheat beat the heat? *Agriculture Ecosystem and Environment,* **126**: 46–58.

Ozberk, I., Atlı, A., Pfeiffer, W., Ozberk, F., and Coskun, Y. (2005). The effect of sunn pest (Eurigaster integriceps) damage on durum wheat: impact in the marketplace. *Crop Protection*, **24**(3): 267-274

Pankaj, Y. K., Kumar, R., Pal, L., Gill, K. S., Nagarajan, R., Sangwan, S., and Panigrahi, S. (2022). Mapping QTLs for morpho-physiological traits related to grain yield under late sown conditions in wheat (*Triticum aestivum* L.). *Cereal Research Communications*, 1-10

Parent, B., Turc, O., Gibon, Y., Stitt, M. and Tardieu, F. (2010). Modeling temperature compensated physiological rates, based on the coordination of responses to temperature of developmental processes. *Journal of Experimental Botany,* **61**: 2057–2069.

Park, Y.I., Park, M.C. and Hong, Y.N. (1994) Correlative changes between photosynthetic activities and chlorophyll fluorescence in wheat chloroplasts exposed to high temperature. *Journal of Plant Biology*, **37**: 37-42.

Pfeiffer, W.H., Trethowan, R.M., van Ginkel, M., Ortiz-Monasterio, I. and Rajaram, S. (2005) Breeding for abiotic stress tolerance in wheat. In: Ashraf M, Harris PJC (eds), Abiotic Stresses – Plant Resistance Through Breeding and Molecular Approaches. Haworth Press, New York, 401–489.

Phadnawis,B.N.and Saini, A.D. (1992). Yield models in wheat based on sowing time and phenological developments. *Annuals of Plant Physiology.* **6**: 52-59.

Pierre, C., Trethowan, R. and Reynolds, M. (2010) Stem solidness and its relationship to water-soluble carbohydrates: association with wheat yield under water deficit. *Functional Plant Biology,* **37**: 166–174.

Pietragalla, J. and Pask, A. (2012). Stomatal conductance. Physiological breeding II: A field guide to wheat phenotyping. CIMMYT, 15-17.

Pinto, R.S., Reynolds, M.P., Mathews, K.L., McIntyre, C.L., Olivares-Villegas, J.J. and Chapman, S.C. (2010) Heat and drought adaptive QTL in a wheat population designed to minimize confounding agronomic effects. *Theoretical and Applied Genetics*, **121**: 1001–1021

Pooja (2017). Physiological studies in wheat genotype under terminal high temperature condition. M.Sc. Thesis CCSHAU, Hisar, India

Pooja and Munjal., R. (2019). Heat tolerant wheat genotypes for late sown conditions identified on the basis of physiological traits. *Journal of Agrometeorology,* **21**(1): 97-100.

Pradhan, G.P., Prasad, P.V.V., Fritz, A.K., Kirkham, M.B., and Gill, B.S. (2012) High temperature tolerance in Aegilops species and its potential transfer to wheat. *Crop Science*, **52**: 292–304.

Prasad, P. V. V., Pisipati, S. R., Ristic, Z., Bukovnik, U. and Fritz, A. K. (2008). Impact of nighttime temperature on physiology and growth of spring wheat. *Crop Science*, **48**(6): 2372-2380.

Przuli, N. and Mladenov, N. (1999) Inheritance of grain filling duration in spring wheat. *Plant Breeding*, **118**: 517-521.

Punia, S.S., Shah, M. and Ranwha, B.R. (2011) Genetic analysis for high temperature tolerance in bread wheat. *African Crop Science Journal*, **19**(3): 149- 163.

Ram, K., Munjal, R., Sunita, P., and 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 Biological Scences and Biotechnology*, **6**(3): 528-37.

Rane, J., Pannu, R.K., Sohu, V.S., Saini, R.S., Mishra, B., Shoran, J., Crossa, J., Vargas, M. and Joshi, K. (2007) Performance of yield and stability of advanced wheat cultivar under heat stress environments of the indo-gangetic plains. *Crop Science*, **47**: 1561-1572

Ray, J. and Ahmed, J.U. (2015) Canopy Temperature Effects on Yield and Grain growth of Different Wheat Genotypes. *IOSR Journal of Agriculture and Veterinary Science*, **8(7)**: 2319-2380.

Raza A, Santella R (2020) Grain and feed annual report. United States Department of Agriculture, Global Agricultural Information Network.

Rebetzke, G. J., Van Herwaarden, A.F., Jenkins, C., Weiss, M., Lewis, D., Ruuska, S., Tabe, L., Fettell, N. A. and Richards, R. A. (2008) Quantitative trait loci for water- soluble carbohydrates and associations with agronomic traits in wheat. *Australian Journal of Agricultural Research,* **59**: 891–905

Rehman, H. U., Tariq, A., Ashraf, I., Ahmed, M., Muscolo, A., Basra, S. M., and Reynolds, M. (2021). Evaluation of physiological and morphological traits for improving spring wheat adaptation to terminal heat stress. *Plants*, **10**(3), 455

Reynolds, M. P. (2002). Physiological approaches to wheat breeding. *Bread wheat: Improvement and production* (No. CIS-3620. CIMMYT.).

Reynolds, M. P., Balota, M., Delgado, M. I. B., Amani, I., and Fischer, R. A. (1994). Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Functional Plant Biology*, **21**(6): 717-730.

Reynolds, M.P., Manes, Y., Izanloo, A. and Langridge, P. (2009) Phenotyping for physiological breeding and gene discovery in wheat. *Annals of Applied Biology,* **155**: 309–320

Reynolds, M.P., Pask, A. and Pietragalla, J. (2012) Introduction - A Field Guide to Wheat Phenotyping. In: Physiological Breeding II, El Batan, Pask, A., Pietragalla, J., Mullan, D. and Reynolds, M (eds.), CIMMYT pp 2–4.

Rezaei, E.E., Siebert, S. and Ewert, F. (2015) Intensity of heat stress in winter wheat phenology compensates for the adverse effect of global warming. *Environmental Research Letters*, **10**: 1-8.

Ristic, Z., Bukovnik, U. and Prasad, P.V.V. (2007) Correlation between heat stability of thylakoid membranes and loss of chlorophyll in winter wheat under heat stress. *Crop Science*, **47**: 2067–2073.

Roohi, E., Sanavy, S.A.M.M. and Siosemardeh, A. (2015) Association of Some Photosynthetic Characteristics with Canopy Temperature in Three Cereal Species under Soil Water Deficit Condition. *Journal Agricultural Science and Technology*, **17**: 1233–1244.

Saari, E. E., and Nayar, S. K. (1998). Experience with wheat rusts in South Asia. Experience with wheat rusts in South Asia., 177-190.

Saini, H.S., Aspinall, D. (1982) Sterility in wheat (Triticum aestivum L.) induced by water deficit or high temperature: possible mediation by abscisic acid. *Austuralian Journal of Plant Physiology*, **9:** 529-537

Salvucci ME and Crafts-Brandner SJ. (2004) Inhibition of photosynthesis by heat stress: the activation state of Rubisco as a limiting factor in photosynthesis. *Physiologia Plantarum,* **120**: 179–186.

Sangwan, S., Ram, K., Rani, P., andMunjal, R. (2018). Effect of terminal high temperature on chlorophyll content and normalized difference vegetation index in recombinant inbred lines of bread wheat. *International Journal of Current Microbiology and Applied Sciences,* **7**(6): 1174-1183.

Saxena, D. C., Prasad, S. S., Parashar, R. andRathi, I. (2016). Phenotypic characterization of specific adaptive physiological traits for heat tolerance in wheat. *Indian Journal of Plant Physiology*, **21**(3): 318-322.

Schapendonk, A. H. C. M., C. J. T. Spitters, and P. J. Groot (1989): Effects of water stress on photosynthesis and chlorophyll fluorescence of five potato cultivars. *Potato Research*, **32**: 17–32

Schapendonk, A. H. C. M., Xu, H. Y., Van Der Putten, P. E. L., and Spiertz, J. H. J. (2007). Heat-shock effects on photosynthesis and sink-source dynamics in wheat (*Triticum aestivum* L.). *NJAS-Wageningen Journal of Life Sciences*, **55**(1): 37-54

Semenov, M.A. and Halford, N.G. (2009) Identifying target traits and molecular for wheat breeding under a changing climate. *Journal of Experimental Botany*, **60**: 2791-2804

Shah, N. and Paulsen, G. (2003) Interaction of drought and high temperature on photosynthesis and grain-filling of wheat. *Plant Soil*, **257**: 219-226

Shah, W. A., Bakht, J., Ullah, T., Khan, A. W., Zubair, M. and Khakwani, A. A. (2006). Effect of sowing dates on the yield and yield components of different wheat varieties. *Journal of Agronomy, **5***(1): 106–110.

Shanmugam, S., Kjaer, K. H., Ottosen, C. O., Rosenqvist, E., Kumari Sharma, D. and Wollenweber, B. (2013). The alleviating effect of elevated CO_2 on heat stress susceptibility of two wheat (*Triticum aestivum* l.) cultivars. *Journal of Agronomy and Crop Science,* **199**(5): 340-350.

Shehrawat, S., Kumar, Y. and Singh, J. (2020). Use of multiple stress indices as a measure of heat tolerance in wheat accessions. *Journal of Cereal Research,* **12**(3): 297-308

Sheikh, S., Behl, R.K., Dhanda, S.S. and Munjal, R. (2010) Chlorophyll fluorescence and membrane thermostability in wheat (*Triticum aestivum* L. em. Thell) under normal and high temperature stress prone late sown conditions. *Cereal Research Communications,* **38**:335–344

Shuja,M.N.,Dure-Nayab M. Ali, A.Iqbal and I.H.Khalil (2010).Evaluating the response of wheat genotypes to forage clipping. *International Journal of Agricultural Sciences*, **12**: 111-114.

Sial, M.A., Arain, M.A., Khanzada, S., Naqvi, M.H., Dahot, M.U. and Nizamani, N.A. (2005) Yield and quality parameters of wheat genotypes as affected by sowing dates and high temperature stress. *Pakistan Journal of Botany,* **37** (3): 575-584.

Singh, H., Kumar, S.N., Ramawat, N. and Harit, R.C. (2017) Response of wheat varieties to heat stress under elevated temperature environments. *Journal of Agrometeorology,* **19:** 17-22.

Singh, J.P., Prasadm, S., Singh, K.N. and Singh, R. (2007). Screening of heat tolerant wheat varieties by membrane thermo stability index in relation to yield and yield attributing traits. *International Journal of Plant Sciences*. **2**(2): 159- 165.

Singh, K., Sharma, S. N. andamp; Sharma, Y. (2011) Effect of High Temperature on Yield Attributing Traitsin Bread Wheat, *Bangladesh Journal of Agricultural research,* **36**(3): 415-426.

Singh, P. and Dwivedi, P. (2015). Morpho -physiological responses of wheat (*Triticumaestivum* L.) genotypes under late sown condition. *Vegetos*, **28** (1): 16-25.

Singh, P. and Jaiswal, J.P. (2013). Assessment of genetic diversity in bread wheat (Triticuma estivum L. em. Thell), genotypes based on agromorphological traits using Mahalanobis „D2‟ statistic. *Environment and Ecology*, **31(**2A): 679-682.

Singha, P., Bhowmick, J. and Chaudhury, B.K. (2006) Effect of temperature on yield and yield components of fourteen wheat (*Triticum aestivum* L.) genotypes. *Environmental Ecology*, **24**: 550–554.

Slafer GA and HM Rawson. (1994). Sensitivity of wheat phasic development to major environmental factors: a reexamination of some assumptions made by physiologists and modellers. *Australian Journal of Plant Physiology*. **21**: 393-426.

Squire, G. R. and Black, J. R. (1981). Stomatal Behaviour in the Field, In: P. I. Jarvis, T. A. Mansfield (Eds.). *Stomatal Physiology*. Cambridge Univ. Press, 223-245.

Suliman, M. S. E., Elradi, S. B. M., Nimir, N. E. A., Zhou, G., Zhu, G., Ibrahim, M. E. H., and Ali, A. Y. A. (2021). Foliar application of 5-aminolevulinic acid alleviated high temperature and drought stresses on wheat plants at seedling stage. *Chilean journal of agricultural research.* **81**(3): 291-299.

Sunita, Munjal, R., Ram, K., Kumar, N., and Dhanda, S. S. (2017) Heat Stress Implications on Yield and yield component in recombinant inbred lines of bread wheat at reproductive stage. *International Journal of Pure and Applied Biosciences*. **5** (3): 1001-1007.

Tahir, I. Q. R. A., Khan, N. U., Gul, S., Ahmed, S., Andleeb, Y., Habib, A., and Hussain, I. (2022). Late planting induced heat stress tolerance in wheat. *Pakistan Journal of Botany*, **54**(3): 795-808.

Talebi, R. (2011). Evaluation of chlorophyll content and canopy temperature as indicators for drought tolerance in durum wheat (*Triticum durum*Desf.). *Australian Journal of Basic and Applied Sciences*, **5(**11): 1457-1462.

Tandon, J.P. (2000) Wheat breeding in India during the twentieth century. *Crop Improvement*, **27**: 1-18

Tewari, A.K. and Tripathy, B.C. (2012) Temperature Stress Induced Impairment of Chlorophyll Biosynthetic Reactions in Cucumber and Wheat. *Plant Physiology*, **117**: 3851-8

Tewolde, H., Fernandez, C.J. and Erickson, C.A. (2006) Wheat cultivars adapted to post-heading high temperature stress. *Journal of Agronomy and Crop Science*, **192:** 111-120.

Tilman D, Balzer C, Hill J and Before BL (2011). Global food demand and the sustainable infensification of agriculture . *Proceedings of the National Academy of Sci*ences**, 108**: 20260-20264

Tiwari, S.K. (1990) Evaluation of productivity constraints of wheat (*Triticum aestivum* L.) under late sown conditions. *Thesis, Ph.D. (Agronomy*), G.B. Pant University of Agriculture and Technology, Pantnagar.

Todorov, D.T., Karanov, E.N., Smith, A.R. and Hall, M.A. (2003) Chlorophyllase activity and chlorophyll content in wild type and eti 5 mutant of Arabidopsis thaliana subjected to low and high temperatures. *Biologia Plantarum*, **46:** 633–636.

Trnka M, M Dubrovsky, D Semeradova and Z Zalud. (2004). Projections of uncertainities in climate change scenarios into expected winter wheat yields. *Theoritical Applied Climatology*. **77**: 229-249.

Tyagi, P.K., Pannu, R.K., Sharma, K.D., Chaudhary, B.D. and Singh, D.P. (2003) Post anthesis dry matter accumulation and its partitioning in different wheat (*Triticum aestivum* L.) genotypes under varying growing environments. *Indian Journal of Agronomy*, **49**: 163-167.

Verma, V., Foulkes, M. J., Worland, A. J., Sylvester-Bradley, R., Caligari, P. D. S., and Snape, J. W. (2004).

Mapping quantitative trait loci for flag leaf senescence as a yield determinant in winter wheat under optimal and drought-stressed environments. *Euphytica*, **135**(3): 255-263.

Vijayalakshmi, K., Fritz, A. K., Paulsen, G. M., Bai, G., Pandravada, S. and Gill, B. S. (2010). Modeling and mapping QTL for senescence-related traits in winter wheat under high temperature. *Molecular Breeding,* **26**(2): 163-175.

Viswanathan, C., and R. Khanna-Chopra, 2001: Effect of heat stress on grain growth, starch synthesis and protein synthesis in grains of wheat (Triticum aestivumL.) varieties differing in grain weight stability. *Journal of Agronomy and Crop Science*. **186**: 1–7.

Vollenweider, P. and Gunthardt Goerg, M.S. (2005) Diagnosis of abiotic and biotic stress factors using the visible symptoms in foliage. *Environmental Pollution,* **137(3)**, 455–465

Wahid, A., Gelani, S., Ashraf, M., and Foolad, M. R. (2007). Heat tolerance in plants: an overview. *Environmental and experimental botany*, **61**(3): 199-223.

Wang, R.X., Hai, L., Zhang, X.Y., You, G.X., Yan, C.S. and Xiao, S.H. (2009) QTL mapping for grain filling rate and yield-related traits in RILs of the Chinese winter wheat population Heshangmai 3X Yu8679. *Theoretical and Applied Genetics,* **118:** 313-325.

Wang, X., Cai, J., Jiang, D., Liu, F., Dai, T. and Cao, W. (2011) Pre-anthesis high-temperature acclimation alleviates damage to the flag leaf caused by post-anthesis heat stress in wheat, *Journal of Plant Physiology,* **168**: 585–593.

Wani S, Sah S (2014) Biotechnology and abiotic stress tolerance in rice. *Journal of Rice Research 2*: 105.https://doi.org/10.4172/jrr.1000e105

Wardlaw, I. F., I. Sofield, and P. M. Cartwright, 1980: Factorslimiting the rate of dry matter accumulation in the grain of wheat grown at high temperature. *Journal of Plant Physiology*.**7:** 387–400

Wiegand, C. L., and J. A. Cuellar, 1981: Duration of grain filling and kernel weight of wheat as affected by temperature. *Crop Sciences.***21**: 95–101

Wollenweber, B., J. R. Porter, and J. Schellberg, 2003: Lack of interaction between extreme high-temperature events at vege-tative and reproductive growth stages in wheat. *Journal of Agronomy and Crop Science.***189**: 142–150

Xiao, D., Tao, F., Liu, Y., Shi, W., Wang, M., Liu, F., and Zhu, Z. (2013). Observed changes in winter wheat phenology in the North China Plain for 1981–2009. *International Journal of Biometeorology*, **57**(2): 275-285.

Yamasaki, T., Yamakawa, T., Yamane, Y., Koike, H., Satoh, K. andKatoh, S. (2002). Temperature acclimation of photosynthesis and related changes in photosystem II electron transport in winter wheat. *Plant Physiology*, **128**(3): 1087-1097.

Yang, J., Sears, R.G., Gill, B.S. and Paulsen, G.M. (2002) Growth and senescence characteristics associated with tolerance of wheat alien amphiploid to high temperature under controlled conditions. *Euphytica,* **126**: 185–193

You, L., Rosegrant, M. W., Wood, S. and Sun, D. (2009). Impact of growing season temperature on wheat productivity in China. *Agricultural and Forest Meteorology*, **149(**6-7)**:** 1009-1014.

Zhang, J., Sun, J., Duan, A., Wang, J., Shen, X., and Liu, X. (2007). Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. *Agricultural water management,* **92**(1-2): 41-47.

Zhao, H., Dai, T., Jiang, D. and Cao, W. (2008) Effects of high temperature on key enzymes involved in starch and protein formation in grains of two wheat cultivars. *Journal of agronomy and crop science*, **194**: 47–54.

Zivcak, M., Brestic, M. and Olsovska, K. (2009) Application of chlorophyll fluorescence for screening wheat (*Triticum aestivum* L.) genotype susceptibility to drought and high temperature.*Vagos*, **82**: 82-87.

ABSTRACT

Title of Thesis:	**Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late sown conditions**
Name of Degree Holder	**Bharti Rawal**
Admission No.:	**2019BS34M**
Title of Degree:	**Master of Science in Plant Physiology**
Name and address of Major Advisor:	**Dr. Anita Kumari** (Assistant Plant Physiologist) Department of Botany and Plant Physiology College of Basic Sciences and Humanities CCS Haryana Agricultural University Hisar – 125 004, (Haryana) INDIA
Degree awarding University/Institute:	**Chaudhary Charan Singh Haryana Agricultural University, Hisar-125004, India**
Year of award of degree:	2022
Major subject:	Plant Physiology
Total number of pages in dissertation:	49 + xiv
Number of words in the Abstract:	268

Key words: Wheat, high temperature, timely sown, late sown, very late sown, photosynthesis

The present investigation was conducted with six wheat genotypes viz. WH147, WH711, WH 1105, WH 1184 WH1021 and HD2967 grown to study the photosynthetic efficiency and nutrient uptake and other physiological traits under timely (TS), late (LS) and very late (VLS) conditions on six wheat genotypes, during rabi season of 2021-22 at screen house, Department of Botany and Plant Physiology, CCS HAU, Hisar. Data were recorded for various morphological traits including number of days to heading, number of days to maturity, plant height (cm), spike length (cm), number of spikelets per spike, number of grains per spike, 1000-grain weight (g), grain yield per plant (g), plant biomass (g), heat susceptibility index. The physiological parameters include canopy temperature, transpiration rate, photosynthetic rate, stomatal conductance, chlorophyll content, anothocynin content, NPK content were studied. Reduction in physiological parameters, growth and yield components was observed in all genotypes under LS and VLS in all genotypes. Photosynthetic rate, maximum in WH1021 followed by HD2967 at 7 and 14 DAA under TS, LS and VLS conditions. Wheat variety HD2967 showed maximum N, P, K content followed by WH1021 under TS, LS and VLS conditions. Plant biomass was maximum in HD2967 followed by WH711 and WH1021. However grain yield (g/plant) and 1000 grain weight was reported maximum in HD2967 followed by WH1021, WH1184, WH1105, WH711 and WH147. Similar results were observed for 1000 grain weight under LS and VLS conditions. Wheat genotype HD2967 followed WH1021 can be considered as heat tolerant on the basis of less reduction in growth, physiological traits, yield and its attributes under LS and VLS as compared to TS conditions.

MAJOR ADVISOR **SIGNATURE OF STUDENT**

HEAD OF THE DEPARTMENT

CURRICULUM VITAE

a) **Name** : **Bharti Rawal**

b) **Date of birth** : **02.02.2000**

c) **Place of birth** : **Jind**

d) **Mother's Name** : **Smt. Sunita Devi**

e) **Father's Name** : **Sh. Dinesh Kumar**

f) **Permanent Address** : **VPO Malar, Jind (Haryana) 126112**

g) **Mobile Number** : **8307537675**

h) **Email Address** : **bhartirawal704@gmail.com**

i) **Academic Qualifications :**

Degree	**University/Board**	**Year of Passing**	**Percentage**	**~Subjects**
10th	Central Board of school Education	2014	89.3%	Hindi, English, Math, Social Studies and Science
10+2	Central Board of school Education	2016	76.0%	Physics, Chemistry, Biology, English and Hindi
B.Sc (Medical)	Kurukshetra University, Kurukshetra	2019	78.0%	Botany, Zoology and Chemistry

Medals/ Honours received: NIL

UNDERTAKING OF THE COPY RIGHT

I, **Bharti Rawal,** Admission No. **2019BS34M**, undertake that I give copy right to the CCSHAU, Hisar of my thesis entitled "**Photosynthetic efficiency and nutrient uptake in wheat grown under timely, late and very late 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.

Signature of student