

**CHARACTERIZATION OF WHEAT GERMPLASM FOR
PHOTOSYNTHETIC PIGMENTS IN RESPONSE TO
FERTILIZER APPLICATION GROWN UNDER LATE
SOWN CONDITION**

By

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2021

CERTIFICATE – I

This is to certify that thesis entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” submitted for the degree of **Master of Science** in the subject of **Plant Physiology** to the CCS Haryana Agricultural University, is a bonafide research work carried out by **Mr. P. S. Kiran. Admn. No. 2019BS37M** under my supervision and that no part of this dissertation has been submitted for any other degree.

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

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CERTIFICATE – II

This is to certify that this thesis entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” submitted by **Mr. P. S. Kiran. Admn. No. 2019BS37M** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar in partial fulfillment of the requirements 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, in collaboration with an external examiner.

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ABBREVIATIONS

Abbreviation	Full form
AGB	Above Ground Biomass
ANOVA	Analysis of Variance
ANTH	Anthocyanin content
CHI	Chlorophyll index
CT	Canopy temperature
CTD	Canopy temperature depression
DAA	Days after anthesis
DAS	Days after sowing
DH	Days to heading
DM	Days to maturity
-F	Without fertilizer (control)
+F	With recommended dose of fertilizer
FAO	Food and Agriculture Organization
FLAV	Flavonoid content
GGR	Grain growth rate
HI	Harvest index
LAI	Leaf area index
MSS	Mean Sum of Squares
NBI	Nitrogen balanced index
NDVI	Normalized difference vegetation index
NNI	Nitrogen nutrition index
NPK	Nitrogen Phosphorus Potassium
NUE	Nutrient use efficiency
OP	Osmotic potential
PAR	Photosynthetically active radiation
PGPR	Plant Growth Promoting Rhizobacteria
PNM	Precise nutrient management
SL	Spike length
TFP	Total factor productivity

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L. em Thell.) is the important and strategic cereal crop for most of the world's populations. It is staple food for about two billion people (36% of the world population). Worldwide, it provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally (Breiman and Graur., 1995). It rises in acreage and production over every other grain crop (including rice, maize), with increasing productivity across the globe, due to its wider adaptability and sustainability under diverse agro climatic conditions (Ramadas *et al.*, 2019). Wheat constitutes one of the key sources of protein in least developed countries and middle-income nations in terms of calories and dietary intake. After China, India is the second largest wheat producer, accounting for around 12% of global wheat production. In India, wheat's area, production, and productivity are 31 mha, 107 mt, and 34 q/ha, respectively. With an area, production, and productivity of 2533 thousand ha, 11876 thousand tonne, and 4687 kg/ha, Haryana supplies roughly 13.5 per cent of wheat to India's central pool (Anonymous 2020).

Agriculture around the world faces numerous problems, including producing of 50% more food for an additional 2.3 billion people by 2050 along with combating poverty and hunger. Reduced quality and quantity of consumed food is a result of enhanced hunger and proliferating population rate which is not providing regular access to nutritious and sufficient food for 25.9 percent of the global population. If this situation is not contemplated then this may lead to severe outcomes (FAO, 2020).

Wheat is high source of protein, rich in fibre and has good quantity of manganese and magnesium in major state. With the growing world's population, increasing the yield of crop is a major concern for wheat growers under changing environmental factors and more particularly temperature. Wheat is primary crop of winter season and has its own definite requirements for temperature, and light for emergence, growth and flowering (Tahir *et al.*, 2009). Among the modern agronomic practices time of sowing and application of fertilizers are imperative for boosting the growth and production of wheat especially under rainfed conditions that affects the yield and productivity of crop. Change in sowing time influences the amount of total protein, leaf chlorophyll content and photosynthetic pigments, probably driven by the differential thermal conditions prevailing during the grain filling period (Jat *et al.*, 2013)

The integrated use of NPK fertilizers plays an important role in wheat production. Wheat yield is greatly influenced by the application of NPK in a balanced proportion at the right time. Inorganic salts particularly Nitrogen (N), Phosphorus (P) and Potassium (K) affect photosynthesis in a direct or indirect way. Direct effects of nutrients on photosynthesis are normally reversible. Indirect effects include the effect on synthesis of enzymes, pigments or

cofactors directly involved in photosynthesis, factors which maintain chloroplast structure, reactions or conditions governing transport or utilization of raw materials, intermediates, or final products. Potassium exerts an indirect effect on photosynthesis through its effect on regulation of stomatal opening.

Nitrogen (N) is a vital component of plant growth and one of the most important yield-limiting factor in crop production in all agro-ecological zones of the world. N is commonly taken up from the soil in two inorganic forms: ammonium (NH_4^+) and nitrate (NO_3^-). Nitrogen is an important component of many essential structural, genetic and metabolic compounds in plant cells. It is an elementary constituent of numerous important organic compounds including amino acids, proteins, nucleic acids, enzymes, and the chlorophyll molecule. Nitrogen fertilizer rate and time of application significantly influence wheat grain yield (Sohail *et al.*, 2013) and quality (Abedi *et al.*, 2010).

Phosphorus (P) is an essential nutrient, and acts as a component of several key plant structural compounds, and as a catalyst in numerous biochemical reactions in plants. Phosphorus is noted especially for its role in capturing and converting light energy into useful organic compounds. It is a vital component of DNA, the genetic "memory unit" of all living things. It is also a component of RNA, the compound that reads the DNA genetic code, to build proteins and other compounds essential for plant structure, seed production, and genetic transfer. Phosphorus stimulates seed formation and its deficiency can be directly related with 1000 grains weight (Iqbal *et al.*, 2003)

Potassium (K) is also one of the third essential plant macronutrient, after Nitrogen and Phosphorus, taken up by crops from soils in relatively large amounts. It also regulates various physiological mechanisms counting in regulation of guard cell for promoting stomatal opening, regulating water status of plants, increasing rate of photosynthesis, aids in starch formation, helps in sugar translocation and enhancing plant's ability to resist disease, insect attacks, cold and drought stresses and other adverse conditions. It also develops strong and healthy root system which further increases the efficiency of the uptake and use of Nitrogen and other nutrients. (Trankner *et al.*, 2018).

Precision nutrient management (PNM) is becoming more important tool in modern agriculture due to its economic and environmental benefits, which necessitates the development of quick and accurate technologies for crop nitrogen status diagnosis during the growing season. (Mulla and Miao., 2016). Because polyphenols are inversely related to crop Nitrogen nutrition status, the Nitrogen balance index (NBI) should emphasise disparities between levels of crop Nitrogen deficits (Cartelat *et al.*, 2005). The presence of high polyphenolics (Phen) concentrations is another indicator of nitrogen deficiency in a crop. Kaniszewski *et al.* (2021) found that leaf Nitrogen content was positively correlated to the Chlorophyll and NBI indices, but negatively correlated to the Flavonoids, under varied Nitrogen fertilizer rates. NBI

represents a more robust proxy of plant N status than Chlorophyll or Flavanols alone, according to Padilla *et al.* (2016). NBI analysis can be used to forecast crop nitrogen status in a non-destructive manner, which in turn provides information about plant nutrient status precisely and timely, helping farmers with economic advantage by reducing overuse of fertilizers.

Therefore, the situation compels to devise a screening technique for identifying varieties which can show significant response to fertilizer application with high NUE for enhancing wheat yield. Under late sown conditions/terminal heat stress, the present investigation entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” was carried out with the following objectives:

Objective of investigation:

- To evaluate the effect of fertilizer application on photosynthetic pigments under late sown condition
- To find correlation between photosynthetic pigments with respect to fertilizer application under late sown condition

CHAPTER II

REVIEW OF LITERATURE

The review of literature covers effect of fertilizer application on wheat with emphasis on quick estimation of plant Nitrogen status and related morphological and physiological parameters such as contribution of photosynthesis to the yield, chlorophyll, anthocyanins, flavonoids and others. The review is being presented under the following headings 1) Wheat: An important cereal 2) Prerequisite for fertilization in wheat production 3) Effect of fertilizer application on physiological parameters 4) Influence of fertilizer application on components of yield 5) Future thrusts

2.1 Wheat: An important cereal

Cereals are critical in meeting the worldwide food demand of a growing population, particularly in poor countries where cereal-based production is the only source of nutrition and calories (Shiferaw *et al.*, 2013). Globally, it occupies about 217 mha (21.8%) of total cultivated area accounting for about 764.39 mt (35.5%) of total food grain production (USDA, 2020). Wheat (*Triticum aestivum* L.) is one of the most widely cultivated cereal crop in the world, and one of the most important staple foods for approximately 2.5 billion people.

India is the second largest producer of wheat in the world and has been cultivated on around 30 million hectares (14 % of global area) to create an all-time high output of 99.70 million tonnes (13.64 percent of global production) with a record average productivity of 3371 kg/ha (MoA & FW, 2018). Cereal is one of the cheapest sources of energy, providing a significant portion of protein (20%) and calories (19%) from ingestion. Wheat has been consumed in various processed forms across the country from prehistoric times (Sharma and Sendhil, 2015). There are various production constraints that differ from crop to crop and between regions. (Fig 2.1)

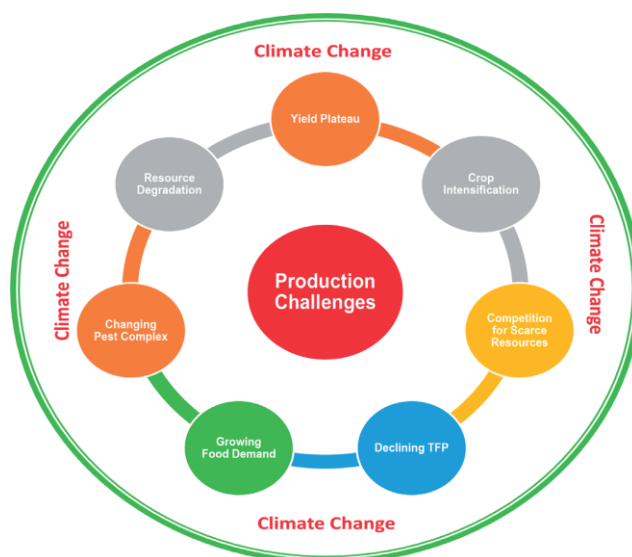


Fig 2.1: Production challenges of wheat in indian constraints

2.2 Prerequisite for fertilization in wheat production

In wheat production, the usage of NPK fertilizers in combination is critical. Wheat yield is greatly influenced by the application of NPK in a balanced proportion at the right developmental stage. Within same species the uptake and allocation of nutrients differ which ultimately affects the physiological and morphological aspects of the crop. Increased cropping intensity and the introduction of high yielding varieties have resulted in significant Nitrogen depletion in soil and a favourable crop storage response to additional Nitrogen in the soil (Ali *et al.*, 2004). Nitrogen being a component of chlorophyll, protein, and nucleic acid, is essential for growth (Jabbar *et al.*, 2009). It accounts for 1.5 to 5% of the dry weight of higher plants. According to Abedi *et al.* (2010), treatments that received more Nitrogen fertilizer generated more grain yield. According to Marino *et al.* (2009), increasing the Nitrogen rate enhanced hulled and unhulled grain production, biomass accumulation, spike/m² number, and kernels/m². Hussain *et al.* (2016) found that increasing Nitrogen levels from 50 to 200 kg/ha enhanced plant height, total number of plants/m², number of grains/spike, number of spikes/m², spike weight, and grain production. Boosted Nitrogen application to 180 kg/ha increased grain yield and other yield components, according to Noureldin *et al.* (2013).

Phosphorus deficiency is widespread in most of the soils and external application of phosphatic fertilizer is regarded vital for crop production and its insufficiency is directly related with 1000 grains weight (Iqbal *et al.*, 2003). Shuaib *et al.* (2009) reported that use of Phosphorus fertilizer in wheat showed a substantial change in grain yield. Alam *et al.* (2003) showed that the plant height significantly increased with increase in rate of Phosphorus application. Rahim *et al.* (2010) reported that thousand grain weight of wheat increased considerably with increasing Phosphorus treatment in the soil. Pawel (2013) demonstrated increased biological yield of winter wheat with Phosphorus fertilizer treatment. El-gizawy (2009) reported that the spikes/m² will increase by increasing Nitrogen and Phosphorus fertilizer application. Ghulam *et al.* (2005) revealed that harvest index did not exhibited significant difference with increasing Phosphorus fertilizer level. Bojović *et al.* (2005) reported that chlorophyll content was enhanced in fertilized soil upon application of Phosphorus fertilizer. A study conducted by Aseffa *et al.* (2021) revealed that application of Phosphorus along with sulphur at 22 and 15 kg ha⁻¹ respectively increased grain yield of wheat by 40.1 % over control.

Potassium (K⁺) is an essential nutrient and its availability controls many biochemical and physiological processes in plants such as enzyme activation, photosynthesis, protein synthesis, osmoregulation, energy transfer, stomatal movement, cation-anion balance and stress resistance (Wang *et al.*, 2014). The addition of Potassium to wheat crops has been shown to improve growth and yield (Janardan *et al.*, 2010). Potassium is required for the efficient functioning of a number of critical biochemical and physiological processes that directly affect

crop productivity. In order to maintain soil fertility and maximize crop yield over the long term, K losses should be restored by balanced and appropriate K fertilization. Potassium is involved in many metabolic pathways and affects crop quality hence it is often called “the quality element” (Hafeez *et al.*, 2019). Arif *et al.* (2017) observed an increase in plant height, fertile tiller number per m², spike length, grain number per spike, thousand grain weight, biomass, and grain yield when Potassium application rates were increased. Ali *et al.* (2013) similarly concluded that Potassium supplementation boosted growth and yield. The addition of Potassium nitrate increased the quantity of grains per spike, which could be attributed to Potassium's beneficial effects on nutrient intake, photosynthetic activity, and source to sink mobilization (Zeng., 1996). Dwivedi (2011) discovered that Potassium treatment aided in increasing the 1000-grain weight of wheat. Hamayun *et al.* (2011) observed an improvement in grain output when the soil was treated with Potassium fertilizer.

Malghani *et al.* (2010) noticed that the usage of NPK fertilizer in conjunction enhanced wheat production when Nitrogen is applied in four splits. Asghar *et al.* (2010) concluded that grain yield of maize and cereal crops increased with application of NPK fertilizer. Tesfaye *et al.* (2021) reported that increased levels of NPK fertilization produced maximum productive tillers per plant, grain yield, 1000 grain weigh, and harvest index in wheat.

2.3 Effect of fertilizer application on physiological parameters

2.3.1 Normalized difference vegetation index

Several vegetative indices like Simple Ratio (SR), Green Normalized Difference Vegetative Index, Global Environmental Monitoring Index and Normalized Difference Vegetative Index are useful for providing more information on land vegetation. Out of these, Normalized Difference Vegetation Index and Simple Ratio are the most widely used vegetation indices (Araus *et al.*, 2001). NDVI is a fast non-destructive way to estimate crop growth capacity. NDVI showed association with leaf Nitrogen content, chlorophyll content and eventually with photosynthetic efficiency of the plant (Tattaris *et al.*, 2016). It is a perfect indicator of growth status, spatial density distribution and phenology of plants. NDVI data had proved to be a robust approach for estimation of abiotic stress among field crops such as wheat (Dangwal *et al.*, 2016). NDVI is a combined estimate of both ground cover (leaf area) and Nitrogen content of canopy and ultimately shows association with photosynthetic efficiency of plant (Pinto *et al.*, 2010).

Aranguren *et al.* (2020) had conducted a study on wheat (*Triticum aestivum* var.cezanne) for understanding the correlation of wheat yield with NDVI. Three soft winter wheat fertilization trials under rainfed conditions were monitored with a RapidScan CS-45 (Holland Scientific, Lincoln, NE, USA) instrument to determine the Normalized Difference Vegetation index (NDVI) at GS30, GS32, GS37, and GS65 growth stages. The threshold NDVI values in the Cezanne variety were 0.7–0.75 at the GS32, GS37, and GS65 growing stages.

They also concluded that the \sum NDVI from GS30 to GS65 explains about 80% of wheat yield variability. The determined ranges of the NDVI values can be used for developing new fertilization strategies that are able to adjust Nitrogen fertilization to wheat crop needs.

Vian *et al.* (2018) had found that there is a significant association of NDVI with shoot biomass and the amount of accumulated Nitrogen in shoots at different growth stages. This information can be used for variable rate of Nitrogen- topdressing fertilization.

2.3.2 Canopy Temperature

Canopy temperature is a direct measurement of the evaporation or transpiration from the leaf surface and is strongly related to stomatal conductance (Rebetzke *et al.*, 2008). Canopy temperature allows more accurate estimates of heat stress on the crop and its yield (Gabaldón-Leal *et al.*, 2016). Indeed, canopy temperature can deviate from air temperature under field conditions, because of the interplay among plant traits, plant water availability, air temperature and humidity, solar radiation, wind velocity, and the ensuing canopy microclimate (Michaletz *et al.*, 2016). Considering canopy instead of air temperature is particularly important when characterizing the effects of compound heat and water stress, and the mitigating potential of irrigation against heat stress. Canopy temperature can be substantially higher than air temperature under water stress conditions (Siebert *et al.*, 2014). Canopy temperature is negatively correlated with yield and biomass under both hot, irrigated and drought condition at vegetative as well as reproductive stages (Reynolds *et al.*, 2007).

Gautam *et al.* (2015) tested 102 germplasm of wheat under late and very late sown conditions and observed that CT showed significant and negative correlation with grain yield and biomass. Mon *et al.* (2016) conducted a two-year field experiment with durum wheat under varying Nitrogen and irrigation levels to know the interactive effect of Nitrogen fertilization and irrigation on grain yield. They noticed that Canopy temperature depression decreased linearly with increasing irrigation level. The study suggested that canopy temperature and weather data that reflects the grain-filling period could be used to improve irrigation and Nitrogen management, respectively. It was concluded that higher irrigation and Nitrogen fertilizer rates resulted in cooler crop canopies.

2.3.3 Nitrogen balanced index

Nitrogen balance index (NBI), has been reported to be more sensitive to crop Nitrogen status than SPAD meter readings. NBI is a promising tool which can help in identifying Nitrogen deficiencies/NUE at various stages of growth. This helps in timely nutrient management with appropriate amounts at the critical stages of crop development. NBI have showed a positive relationship with leaf Nitrogen status and yield that can be exploited as a quick and efficient method to forecast plant Nitrogen status. This index can even provide polyphenol content which used to be increased under Nitrogen deficient condition.

Kaniszewski *et al.* (2021) found that leaf Nitrogen content was positively correlated to the Chlorophyll and NBI indices, but negatively correlated to the Flavonoid content, under varied Nitrogen fertilizer rates. They suggested that NBI can be a valuable innovative tool for the sustainable assessment of the nitrogen status in plants. NBI can be used to forecast crop yield, that have significant impact on the economic trading and food production monitoring.

NBI represents a more robust proxy of plant Nitrogen status than Chlorophyll or Flavanols alone, according to Padilla *et al.* (2016) and Tremblay *et al.* (2007). Padila *et al.* (2016) conducted a study in plants where they found that NBI was the most sensitive index for measuring plant Nitrogen status which had a strong relationship to crop Nitrogen Nutrition Index (NNI) during the reproductive and harvest phases. They also noticed that there was variability in NBI values between cropping seasons and a lack of sensitivity in the range of optimal to slightly excessive crop Nitrogen status.

2.3.4 Chlorophyll index

Leaf chlorophyll is a key indicator of leaf greenness, and it is often used to investigate leaf nutrient deficiencies and changes in chlorophyll (Ali *et al.*, 2017). Chlorophyll plays key role in photon absorption, transmission and transportation and is the master molecule related to photosynthesis in leaves. Canopy chlorophyll content is also an indicator of seasonal carbon uptake in forest ecosystems (Croft *et al.*, 2015). Significant correlations between chlorophyll content and leaf Nitrogen have been reported in many agricultural crops such as Wheat, Rice, Maize, Cotton and Groundnut (Kalacska *et al.*, 2015). Chlorophyll content, LAI and leaf dry weight are positively influenced by Nitrogen fertilizer application. (Hokmalipour & Darbandi, 2011).

Liu *et al.* (2019) revealed that increasing the amount of Nitrogen fertilizer may improve the chlorophyll content in crop leaves, by enhancing the photosynthetic rate. They noticed that the leaf chlorophyll content of peanut under all Nitrogen fertilizer treatment regimes was significantly higher than that of control. Lu *et al.* (2019) compared the leaf chlorophyll balance index with above ground mass and formulated a crop modelling tool in rice. The statistical diagnostic results confirmed that the adjustment approach of fertilizer, with chlorophyll index increased the precision of the above ground mass simulation. The proposed rice estimation method for Above ground biomass (AGB) that was based on leaf CHI, PAR and LAI.

2.3.5 Anthocyanin content

Anthocyanin pigments are flavonoid pigments that help plants respond to biotic and abiotic stress. The pigmentation of anthocyanins in different regions of plants is linked to their ability to adapt to environmental stress (Khlestkina., 2013).

Lyu *et al.* (2020) noticed that the anthocyanin content reduced in plants grown under low Nitrogen concentration. They concluded that Nitrogen deficiency has been reported to enhance anthocyanin pigmentation in plants. Mbarki *et al.* (2018) found that higher flavonol

and anthocyanin accumulation in coloured wheat germplasm showed a faster development of adaptive responses of wheat germplasm to salt stress.

Hilbert *et al.* (2003) reported that the Nitrogen supply decreases the anthocyanin content, changes the anthocyanin composition and favors the degradation of anthocyanins in plants. Heimler *et al.* (2017) reviewed that in almost all plants Nitrogen fertilization caused a decrease in polyphenols content.

2.3.6 Flavanoid content

Flavonoids, a type of low-weight phenolic compound, have multiple functions in plants, *viz.* UV protection, disease and insect defence, microbe signalling, auxin transport modulation, and pigmentation (Winkel-Shirley, 2001). Due to a variety of alteration processes in flavonoids production, more than 9000 distinct flavonoids have been found (Ververidis *et al.*, 2007). All flavonoids are produced from the general phenylpropanoid route, as well-known pathway in secondary plant metabolism, despite their diversity in activities and structures. Stewart *et al.* (2001) reported an increase in flavonol accumulation in mature vegetative tissues of plants upon Nitrogen stress conditions.

Liu *et al.* (2020) conducted a study with wheat germplasm Yunmai-47 and faba bean germplasm Yundou-8363 and carried out soil and hydroponic experiments to examine the influences of intercropping and Nitrogen supply on flavonoid exudation in roots. The study revealed that wheat intercropped with faba bean secreted more flavonoids than monocropped wheat at its tillering and flowering stages. It was also noticed that secretion of flavonoids in wheat roots decreased with increased Nitrogen supply.

2.3.7 Osmotic potential

Osmotic potential (ψ_s) results from dissolved solutes in cell sap and is proportional to solute concentration and inversely proportional to cell water potential. Osmotic potential in plants is always negative and decreases as solutes concentration increases during plant dehydration. Zaidi *et al.* (2014) revealed that at higher salt levels, the crop yields are reduced so drastically that crop cultivation is not economical without soil amendments. The addition of salts to water lowers its osmotic potential, resulting in decreased availability of water to roots and thus exposes plants to secondary osmotic stress. Under stress conditions, like salinity and/or drought to maintain appropriate metabolic activity it is very important to maintain relative water content in plant cells (Avramova *et al.*, 2019).

Kanwal *et al.* (2017) conducted a study in two wheat varieties NARC 2009 and NARC 2011 to evaluate the effect of PGPR, compost and irrigation. The study revealed that osmotic potential of the leaf decreased in the plant growing under water stress as compared to the plants growing under well-watered conditions. Results of PGPR in combination with compost and mineral fertilizer were more effective, showing 24.09% increase in osmotic potential as compared to control followed by the plants treated with PGPR and mineral fertilizer.

2.3.8 Grain growth rate

The source to sink relationship is significantly affected in wheat varieties when exposed to varying fertilizers and at different sowing dates. It was observed that insufficient availability of K, results in reduced grain filling period that ultimately resulted into smaller and poor-quality seeds (Ashraf *et al.*, 2011). Grain growth rate was studied in four wheat germplasm under normal sown and late sown condition. Under late sown condition, reduction in grain growth rate ranges from 6.59% to 10.25%. Grain growth rate (GGR) at 14 and 28 days after anthesis (DAA) showed positive correlations with grain weight per spike and thousand grain weight (Rani *et al.*, 2018). Ali *et al.* (2019) reported that Potassium at a rate of 80 kg ha⁻¹ showed a pronounced grain growth rate and had resulted in a larger number of grains spike⁻¹ and heavier grains.

2.4 Influence of fertilizer application on components of yield:

Ullah *et al.* (2018) observed that increasing the levels of nitrogen can increase maximum number of tillers, plant height and biological yield. Nasri *et al.* (2017) reported that increasing the Nitrogen levels significantly improved the number of spikelets per spike, grains per spike, grain weight and number of spikes per unit area. Rahman *et al.* (2014) concluded an increased plant height due to different doses of Nitrogen. Abdalla *et al.* (2021) reported increased NPK levels had a positive effect over grain yield of wheat cultivars.

Shuaib *et al.* (2009) reported that use of Phosphorus fertilizer in wheat showed a substantial change in grain yield. Alam *et al.* (2003) showed that the plant height significantly increased with Phosphorus application. Rahim *et al.* (2010) reported that thousand grain weight of wheat increased considerably with increasing Phosphorus treatment. Pawel (2013) demonstrated that biological yield of winter wheat rose with Phosphorus fertilizer treatment. El-gizawy (2009) deduced that the spikes/m² will rise by increasing Nitrogen and Phosphorus fertilizer application. Ghulam *et al.* (2005) revealed that harvest index did not exhibited significance with increasing Phosphorus fertilizer level.

Arif *et al.* (2017) observed an increase in plant height, fertile tiller number per square meter, spike length, grain number per spike, thousand grain weight, biomass, and grain yield when Potassium rates were increased. Ali *et al.* (2013) similarly concluded that Potassium supplementation boosted growth and yield. The addition of Potassium nitrate increased the number of grains per spike, enhanced nutrient intake and photosynthetic activity (Zeng, 1996). Potassium has a positive impact on water use efficiency by promoting plant growth and cell division, synthesizing hydrocarbons and proteins, and higher source to sink mobilization (Marschner, 1995). It was discovered that Potassium treatment resulted in increasing the 1000-grain weight of wheat. Dwivedi (2011) and Hamayun *et al.* (2011) both observed an improvement in grain output when the soil was treated with Potassium fertilizer.

Malghani *et al.* (2010) indicated that plant height, number of tillers/m², number of spikes/m², number of grains/spike, 1000 grain weight and grain yield rose linearly with consecutive increase in NPK.

2.5 Future thrusts

There is a limited scope for increasing the crop acreage besides the tremendous increase in population, the production target has been fixed at 140 mt by 2050 to assure the growing demand (ICAR IIWBR, 2015). The existing average yield has to be increased from 34 q/ha to 47 q/ha by 2050, along with the production threats and challenges. It is of utmost importance to develop tailored germplasm for specific wheat-growing regions in order to break the yield barriers in a gradual manner in the coming decades.



Fig 2.2: Existing production and target of wheat for 2050

The following strategies can be focused upon to achieve this optimistic production target (Sharma *et al.*, 2014):

1. Improvement of wheat under conventional methods
 - a) Exploitation of heterosis for developing hybrids
 - b) Pre-breeding programme by broadening the varieties genetic bases
 - c) Development of new plant types
 - i) Desired canopy structure
 - ii) Rapid leaf area development
 - iii) Rapid nutrient uptake
 - iv) Increasing lodging resistance
2. Biotechnological interventions
 - a) Marker assisted breeding
 - b) Wheat genome sequence and associated genomic tools
 - c) Potential of wheat transgenics and possibilities of greater public acceptance
 - d) Functional characterization of genome
3. Tackling disease resistance and abiotic stress-climate change
4. Encouraging scientific temper and institutional innovativeness

CHAPTER III

MATERIALS AND METHODS

The present study entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application under late sown condition**” was conducted at Wheat Research Farm, Department of Genetics & Plant Breeding, CCS HAU, Hisar during rabi 2020-21.

3.1 Plant material

Two hundred and twenty-eight wheat germplasm lines were obtained from CIMMYT (International Maize and Wheat Improvement Center), Mexico through Department of Genetics and Plant Breeding, COA, Hisar. The list of wheat germplasm lines used for the study are described in (Annexure I).

3.2 Methods

3.2.1 Raising of the crop

The crop was sown in two sowing environments viz. control (without fertilizer) and with recommended dose of fertilizer (NPK at 100:40:30 kg ha⁻¹) on 16th December, 2020 at Wheat Research Area, Department of Genetics and Plant Breeding, CCS HAU, Hisar in completely randomized block design. The plot consisted of two rows of two-meter length with a spacing of 20 cm. Irrigation scheduling in both treatments was at 30 DAS (Crown Root Initiation Stage). Fertilizer application was done by broadcasting method.

3.2.2 Meteorological Data

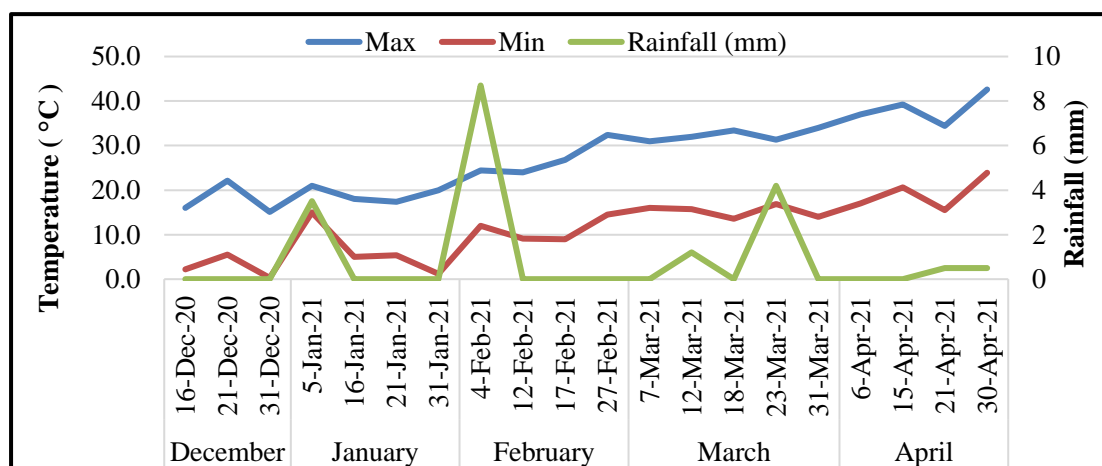


Fig 3.1: Monthly data of maximum and minimum temperature with rainfall during cropping season 2020-21

Monthly data of Temperature (°C), Rainfall (mm), Relative humidity and Sunshine (hrs) are given in (Annexure II).

3.3 Physiological studies

Flag leaf of selected plants were randomly chosen and tagged (ten per germplasm). The tagged plants were used to measure physiological traits from grain filling stage (from date of

anthesis and at interval of ten days till maturity). Three spikes per plot were taken from day of anthesis to day of maturity at an interval of seven days for measuring grain growth rate. The observations for all the parameters were recorded in triplicate.

3.3.1 Normalized Difference Vegetation Index (NDVI)

The Normalised Difference Vegetation Index (NDVI) was determined using a hand-held optical sensor unit called a Greenseeker (Model 505, NTech Industries, Inc., Ukiah, CA, USA). Around midday on sunny days, measurements were acquired over the sub plots at a height of roughly 0.40–0.60 m. In both conditions, readings were collected at 70, 90, and 105 DAS.

3.3.2 Canopy Temperature (°C)

Measurements of canopy temperature (CT) were taken with a hand-held infrared thermometer (IRT), (Model AG-42, Tele temp crop Fullerton). Measurements were obtained around 0.5 m from the plot's edge and approximately 0.5 m above the canopy at an angle of approximately 30-60° from the horizontal. On sunny days, between 12:00 and 14:00 hours readings were collected at 70, 90, and 105 DAS.

3.3.3 Nitrogen balanced index (NBI)

The Nitrogen balanced index was measured using ForceA Dualex optical leaf clipper meter (FORCE-A, Orsay, France) on clean, dry, green flag leaf of three plants of all the germplasm under both conditions were selected and kept between the sensor avoiding the central rib of the leaf. NBI is the ratio of chlorophyll/flavonols (related to Nitrogen/carbon allocation), used as an indicator of plant Nitrogen status. Dualex measures the chlorophyll content of leaf by a transmittance ratio at two different wavelengths. It measures the transmitted light in the far-red region absorbed by chlorophyll along with the transmitted light in the near-infrared region as a reference. Dualex measures flavonols content of the leaf's epidermis by a differential ratio of chlorophyll fluorescence. This principle of measurement is called the screening effect of polyphenols on chlorophyll fluorescence.

3.3.4 Chlorophyll index

The Chlorophyll index was measured using ForceA Dualex optical leaf clipper meter (FORCE-A, Orsay, France) on clean, dry, green flag leaf of three plants of all the germplasm under both conditions were selected and kept between the sensor avoiding the central rib of the leaf. The leaf chlorophyll content can rapidly and accurately be assessed from light transmission. A first wavelength very close to the red quantifies the chlorophyll and a second in the near infrared can take into account the effects of leaf structure.

3.3.5 Flavonoid content

The flavonoid content was measured using ForceA Dualex optical leaf clipper meter (FORCE-A, Orsay, France) on clean, dry, green flag leaf of three plants of all the germplasm under both conditions were selected and kept between the sensor avoiding the central rib of the

leaf. Near-infrared chlorophyll fluorescence is measured under a first reference excitation light not absorbed by polyphenols. It is compared to a second sampling light specific to a particular type of polyphenols, green for anthocyanins or UV-A for flavonols. It is expressed in relative absorbance unit.

3.3.6 Anthocyanin content

The anthocyanin content was measured using ForceA Dualex optical leaf clipper meter (FORCE-A, Orsay, France) where clean, dry, green flag leaf of three plants of all the germplasm under both 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)

3.3.7 Osmotic potential (ψ)

The osmotic potential of the plants was determined by removing the flag leaves. These leaves were placed in sealed syringes and stored at -18°C in a deep freezer. Sap was collected from these leaves using filter paper discs and Ψ s was determined using a Vapor Pressure Osmometer (Model 5100-B, Wescor Inc. Logan, Utah, USA). The osmometer was calibrated using sodium chloride osmolality reference standards (Wescor mc, USA). The osmometer data, which were acquired in millimoles per kg, were converted to molality and then to (-) bars using a calibration curve. The values were in mmol kg^{-1} and were converted to MPa using the conversion factor below.

$$1000 \text{ mmol kg}^{-1} = 2.5 \text{ MPa}$$

$$2.5 \text{ MPa} = 25 \text{ bars}$$

3.3.8 Grain growth rate (mg/day)

For grain growth study, three ears were harvested from each germplasm from day of anthesis at seven days interval. It was continued up to physiological maturity. The harvested ears were oven dried at 70°C for 72 hours. Ten grains of each germplasm were separated from the middle of each spike & then weight was taken with analytical balance. Grain growth rate was calculated by following formula:

$$\text{Grain growth rate(mg/day)} = (W_2 - W_1)/(T_2 - T_1)$$

Where

W_1 = Grain weight at initial time

W_2 = Grain weight at final time

T_1 = Initial time

T_2 = Final time

3.4 Yield and its component

3.4.1 Days to heading

The date on which 50% of ear emerged out from flag leaf in almost 50% of plants of a germplasm was recorded. Days from sowing to date of heading were calculated and used as days to heading.

3.4.2 Days to maturity

The date on which 75% of plants of a germplasm were physiologically matured was recorded and the numbers of days from date of sowing were calculated to note down days to maturity.

3.4.3 Plant height (cm)

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

3.4.4 Number of spikelets per spike

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

3.4.5 Spike length (cm)

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

3.4.6 Number of productive tillers per meter row length

At maturity, tillers bearing fully developed spikes in one-meter row length were counted and their average was taken.

3.4.7 Biomass (g)/m

At maturity, plants were harvested from the base of main stem and weighed using an electronic balance in gram.

3.4.8 Number of grains/ spikes

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

3.4.9 Grain weight (g)/ spike

The weight of total grains per spike from two spikes in each germplasm was taken in grams & average was recorded.

3.4.10 Grain yield (g)/m

Grain yield of each germplasm was recorded in grams per meter row length.

3.4.11 1000-grain weight (g)

Thousand clean & filled grains were randomly chosen and weighed. The measurement was taken in grams using electronic balance from each germplasm.

3.4.12 Harvest Index (%)

Harvest index for each of the germplasm was computed using the following formula;

$$\text{Harvest index (\%)} = \frac{\text{Grain yield per plant (g)}}{\text{Biomass per plant (g)}} \times 100$$

3.5 Soil analysis

The soil samples of 100 g were collected from both the treatments (without fertilizer and with fertilizer) was collected at the time of sowing and harvest between the rows of standing crop in a zig zag manner. The samples were collected from a depth of 15 cm by using soil auger and stored in polythene bags. These samples were analysed for Nitrogen, Phosphorus and Potassium (NPK) by Alkaline Potassium permanganate method (Asija and Subbiah, 1956), Olsen's method (Olsen et al., 1954) and Flame photometric method (Hanway and Heidel, 1952) methods respectively.

Table 3.1: Soil NPK content (kg ha⁻¹) in without fertilizer and with fertilizer plot at different days

SOIL NPK CONTENT (kg ha ⁻¹)						
OBSERVATION STAGES	WITHOUT FERTILIZER			WITH FERTILIZER (RDF)		
	N	P	K	N	P	K
BEFORE SOWING	133.32	16.15	328.21	134.12	17.12	331.20
AT HARVEST	109.46	13.26	286.20	148.73	23.13	338.30

3.6 Statistical analysis

3.6.1 Analysis of variance (ANOVA)

The data was analysed by analysis of variance (ANOVA) for two factor under randomized block design (RBD) using OPSTAT software available on www.hau.ac.in home page and CD at 5% level of significance was calculated.

The data recorded on different characters during the course of investigation were subjected to statistical analysis by using the analysis of variance technique for randomized block design as suggested by Panse and Sukhatme (1967). The skeleton of analysis of variance and formula used for various estimation are given below.

Table 3.2: ANOVA table

Source of variation	d.f.	Mean sum of squares	F value
Replication	r-1	SSR/r-1	MSR/MSE
Factor A (germplasm)	k-1	SSA/k-1	MSA/MSE
Factor B (fertilizer)	j-1	SSB/j-1	MSB/MSE
Interaction (A x B)	(k-1) (j-1)	SSAB/(k-1) (j-1)	
Error	(kj-1) (r-1)	SSE/rkj-1	
Total	rkj-1		

Where,

r : Number of replications

k : Number of factor A (germplasm)

j : Number of factor B (fertilizer)

d.f : Degree of freedom

SSR : Replication sum of squares

SSA : Factor A sum of squares

SSB : Factor B sum of squares

MSR : Replication mean sum of squares

MSA : Factor A mean sum of squares

MSB : Factor B sum of squares

MSE : Error mean sum of squares

SSE : Error sum of square

The Mean Sum of Squares (MSS) of all the parameters are described in Annexure III.

3.6.2 Parameters of variability

3.6.2.1 Mean

The mean value of each character was calculated by dividing the sum total of observations by corresponding number of observations:

$$\bar{x} = \frac{\sum x_i}{N}$$

Where,

N : Total number of observations

x_i : Observation of ith treatment

3.6.2.2 Range

Difference of the highest and the lowest values for each character was calculated.

3.6.2.3 Critical Difference (CD)

Critical difference was calculated by using the following formula:

$$CD = SE(d) \times 't'$$

Where,

SE (d): Standard error (difference)

't': Tabulated t value at 1 or 5 % level of significance and error degree of freedom

3.7 Correlation co-efficient analysis

To determine the degree of association of physiological parameters with yield, the Pearson's correlation coefficients (r) were calculated available in OPSTAT software.

Coefficients of correlation were determined by using the variance and covariance components as suggested by Al-Jibouri et al. (1958).

$$r(x, y) = \frac{\text{cov}(x, y)}{\sqrt{\sigma^2(x) + \sigma^2(y)}}$$

Where,

r (x, y): Correlation coefficient

cov: Covariance of x and y

$\sigma^2(x)$: Variance of x

$\sigma^2(y)$: Variance of y

The calculated value of 'r' was compared with table 'r' value with n-2 degrees of freedom at 5% and 1% level of significance, where, n refers to number of pairs of observation.



Data recording during the research work

CHAPTER IV

EXPERIMENTAL RESULTS

The present investigation on “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” were conducted with two hundred twenty-eight germplasm at research area of Wheat and Barley Section of Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar during rabi (2020- 21). The crop was sown in two environments viz. without fertilizer (-F) and with recommended dose of fertilizer (+F) conditions with three replications under late sown conditions. The results achieved are summarized as below:

4.1 Physiological Traits: -

Normalized difference vegetation index (NDVI) and canopy temperature ($^{\circ}\text{C}$) were observed at 70, 90 and 105 DAS in all wheat germplasm under both -F and +F conditions.

4.1.1 Normalized Difference Vegetation Index (NDVI)

At 70 DAS, the mean value of germplasm grown under -F condition was found to be 0.61 with a range of 0.39 - 0.79. However, for +F condition with a range of 0.53-0.83, the mean value was 0.70. As 90 DAS was observed, the mean value comes out to be 0.48 in germplasm grown under -F condition with a range of 0.32-0.61 whereas the mean was 0.56 in germplasm grown under +F condition with a range of 0.45-0.70.

Table 4.1: Normalized difference vegetation index at 70, 90 and 105 DAS in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	NDVI					
	70 DAS		90 DAS		105 DAS	
	-F	+F	-F	+F	-F	+F
Mean	0.61	0.70	0.48	0.56	0.16	0.23
Range	0.39-0.79	0.53-0.83	0.32-0.61	0.45-0.70	0.12-0.31	0.12-0.40
CD at 5 %	G = 0.020, F = 0.002, G x F = 0.028		G = 0.016, F = 0.001, G x F = 0.022		G = 0.007, E = 0.001, G x F = 0.010	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

At 105 DAS, the mean of 0.16 was observed in germplasm grown under -F condition with a range of 0.12-0.31 whereas, the mean was 0.23 in germplasm grown under +F condition with a range of 0.12-0.40 (Table 4.1).

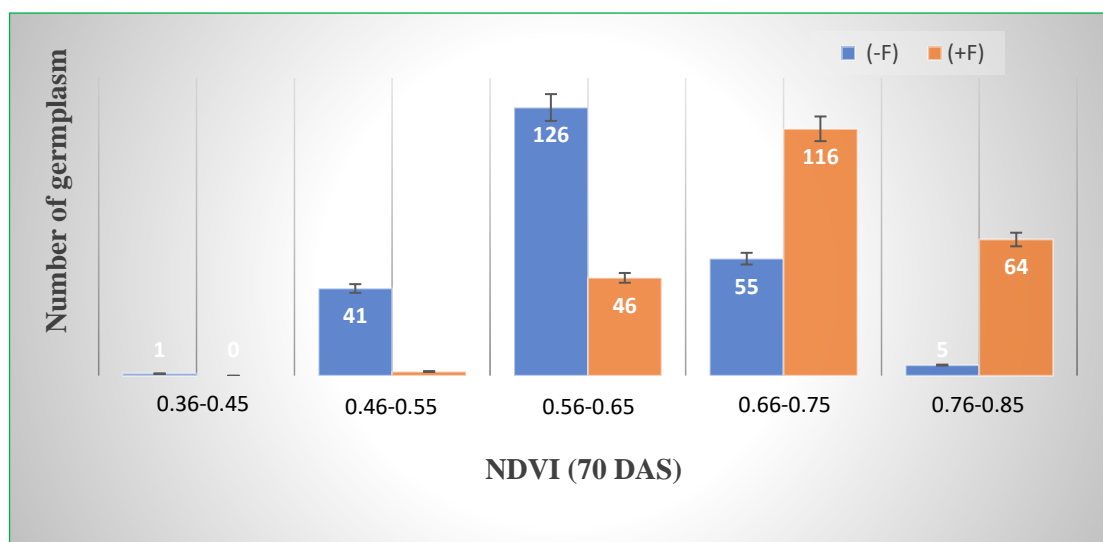


Fig 4.1: Frequency distribution graph for Normalized Difference Vegetation Index (NDVI) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 70 DAS

Maximum NDVI at 70 DAS was noticed in wheat germplasm 22 (0.79) followed by 23 (0.78), 53 (0.77), 49 (0.76), 52 (0.75), 54 (0.74), 164 (0.73), 43 (0.73), 38 (0.73) and 20 (0.73) under -F condition while in germplasm 119 (0.83), 53 (0.82), 51 (0.81), 22 (0.81), 59(0.80), 52(0.80), 227 (0.80), 167 (0.80), 126 (0.80) and 225 (0.79) under +F condition. However minimum NDVI was observed in germplasm 73 (0.39) followed by 90 (0.47), 1 (0.48), 60 (0.49), 15 (0.50), 134 (0.50), 136 (0.50), 139 (0.50), 58 (0.51) and 17 (0.51) under -F condition while 73 (0.53) followed by 1 (0.54), 9 (0.56), 15 (0.56), 4 (0.57), 134 (0.57), 136 (0.57), 139 (0.57), 11 (0.58) and 6 (0.59) had minimum NDVI in +F condition. The maximum germplasm showed a range from 0.56 to 0.65 under -F condition whereas it was within a range of 0.66 to 0.75 under +F condition (Fig. 4.1).

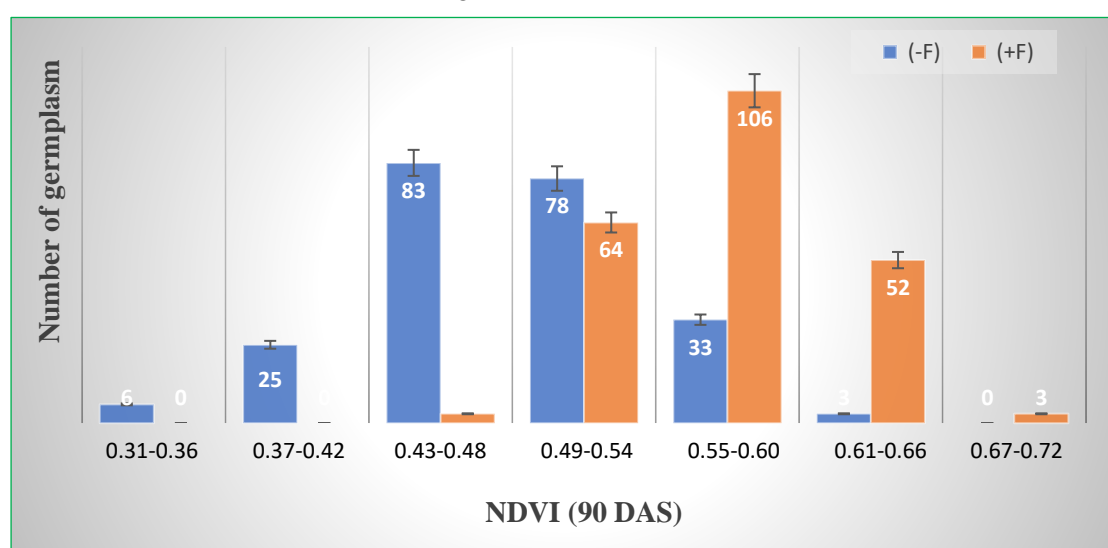


Fig 4.2: Frequency distribution graph for Normalized Difference Vegetation Index (NDVI) in Wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 90 DAS

At 90 days after sowing, maximum NDVI was observed in germplasm 53 (0.61) followed by 38 (0.61), 36 (0.60), 54 (0.59), 45 (0.59), 206 (0.58), 167 (0.58), 101 (0.58), 51 (0.58) and 50 (0.58) under -F condition while maximum under +F condition germplasm are 206 (0.70) followed by 109 (0.66), 53 (0.66), 116 (0.65), 113 (0.65), 213 (0.64), 194 (0.64), 167 (0.64), 166 (0.64) and 155 (0.64). However, minimum NDVI was observed in germplasm 73 (0.32) followed by 59 (0.35), 137 (0.35), 139 (0.35), 228 (0.35), 31 (0.35), 1 (0.36), 141 (0.36), 143 (0.36) and 3 (0.37) under -F condition while 137 (0.45) followed by 141 (0.46), 29 (0.46), 25 (0.48), 32 (0.48), 65 (0.48), 73 (0.48), 90 (0.48), 143 (0.48) and 147 (0.48) had minimum NDVI under +F condition. Maximum germplasm showed range from 0.43 to 0.48 under -F condition whereas it was within a range of 0.55 to 0.60 under +F condition (Fig. 4.2).

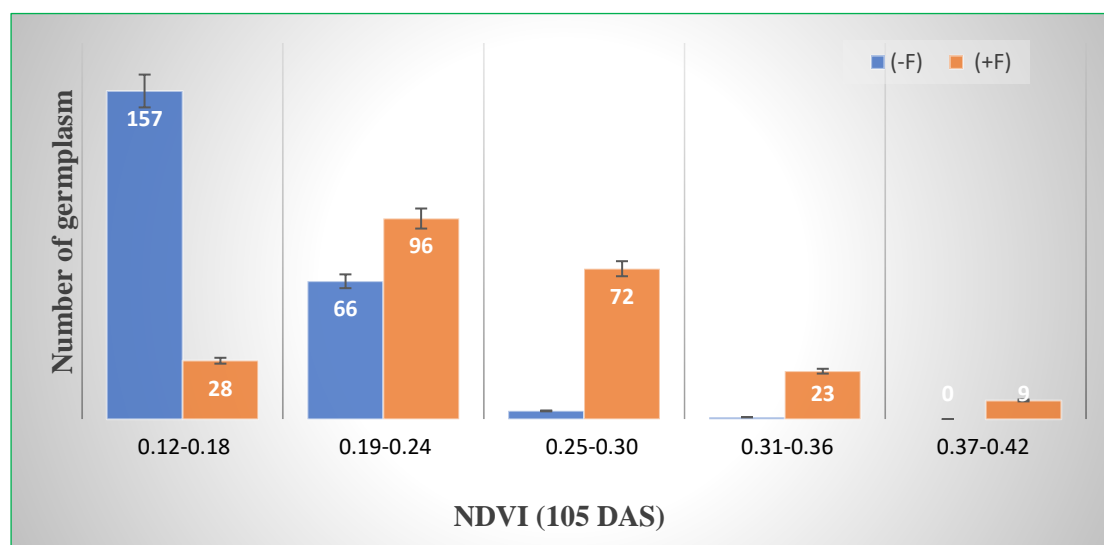


Fig 4.3: Frequency distribution graph for Normalized Difference Vegetation Index (NDVI) in Wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 105 DAS

At 105 days after sowing, maximum NDVI was observed in 71 (0.31) followed by 52 (0.28), 49 (0.27), 166 (0.26), 153 (0.25), 210 (0.23), 167 (0.23), 99 (0.23), 53 (0.23) and 45 (0.23) under -F condition while maximum under +F condition germplasm are 54 (0.40) followed by 53 (0.40), 12 (0.40), 57 (0.37), 49 (0.37), 119 (0.36), 112 (0.36), 104 (0.36), 56 (0.36) and 79 (0.35). However, minimum NDVI was observed in 6 (0.12) followed by 13 (0.12), 20, 21, 24, 31, 38, 57, 63 and 65 (0.12) under -F condition while 72 (0.12) followed by 137 (0.12), 24 (0.13), 111 (0.14), 9 (0.15), 29 (0.15), 59 (0.15), 64 (0.15), 19 (0.16) and 32 (0.16) had minimum NDVI under +F condition. Maximum number of germplasm showed a range from 0.12 to 0.18 under -F condition whereas it was within a range of 0.19 to 0.24 under +F condition (Fig. 4.3).

4.1.2 Canopy Temperature (°C)

At 70 DAS, CT (°C) was observed with a mean of 27.4 under -F condition with a range of 25.1 to 29.3 whereas the mean was found 26.3 under +F condition with a range of 24.2 to

28.7. At 90 DAS, values for CT were observed with a range of 27.9 to 31.3 and a mean of 29.6, grown under -F condition, whereas the mean was 28.3 in germplasm grown under +F condition with a range of 26.4 to 29.7.

Table 4.2: Canopy temperature (°C) at 70, 90 and 105 DAS in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	CT(°C)					
	70 DAS		90 DAS		105 DAS	
	-F	+F	-F	+F	-F	+F
Mean	27.4	26.3	29.6	28.3	36.0	33.6
Range	25.1-29.3	24.2-28.7	27.9-31.3	26.4-29.7	32.4-39.8	29.7-38.1
CD at 5 %	G = 0.765, F = 0.0.072, G x F = 1.082		G = 0.812, F = 0.076, G x F = 1.148		G = 1.017, F = 0.095, G x F = 1.439	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Values for CT (°C) at 105 DAS was observed with a mean of 36.0 in germplasm grown under -F condition with a range of 32.4 to 39.8 whereas the mean was 33.6 for +F grown germplasm with a range of 29.7 to 38.1 (Table 4.2).

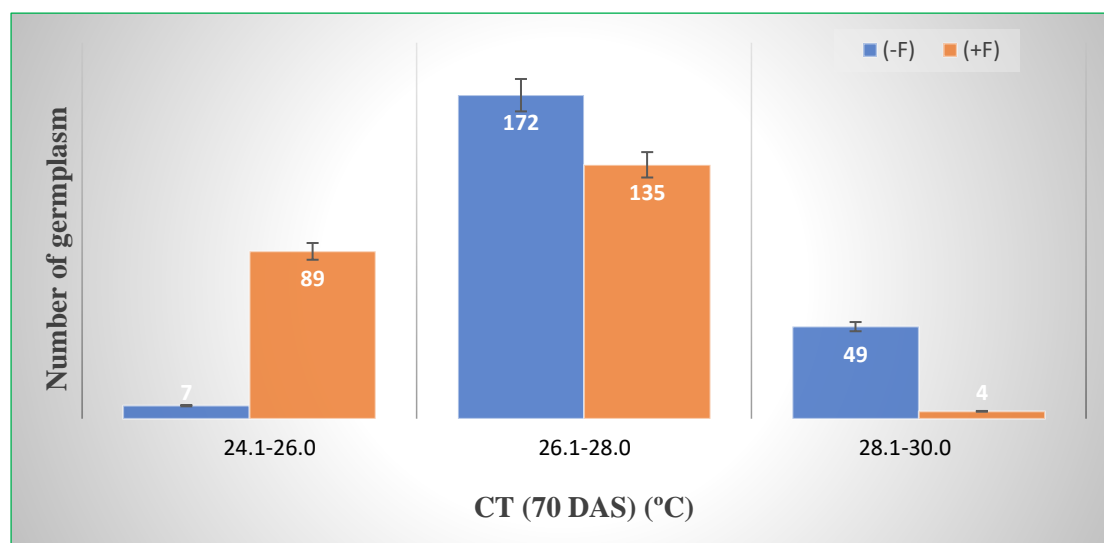


Fig 4.4: Frequency distribution graph for canopy temperature (°C) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 70 DAS

Maximum CT (°C) at 70 DAS was noticed in wheat germplasm 90 (29.3) followed by 10 (29.3), 7 (29.0), 27 (28.9), 32 (28.9), 9 (28.9), 142 (28.8), 174 (28.6), 147 (28.6) and 154 (28.5) under -F condition while in germplasm 142 (28.7), 189 (28.4), 141 (28.2), 5 (28.2), 136(27.9), 7(27.9), 193 (27.9), 140 (27.9), 131 (27.9) and 17 (27.9) under +F condition. However minimum CT (°C) was observed in germplasm 210 (25.1) followed by 209 (25.2) 213 (25.3), 216 (25.4), 86 (25.6), 217 (24.4), 212 (25.7), 218 (26.0), 52 (26.1) and 53 (26.1) under -F condition while 217 (24.2) followed by 95 (24.4) 155 (24.7), 100 (24.8), 118 (24.8), 164

(24.8), 167 (24.8), 68 (24.9), 179 (24.9) and 97 (25.0) had minimum CT (°C) under +F condition. Range of values shown by maximum germplasm under 70 DAS was 26.1 to 28.0°C under both conditions (Fig. 4.4).

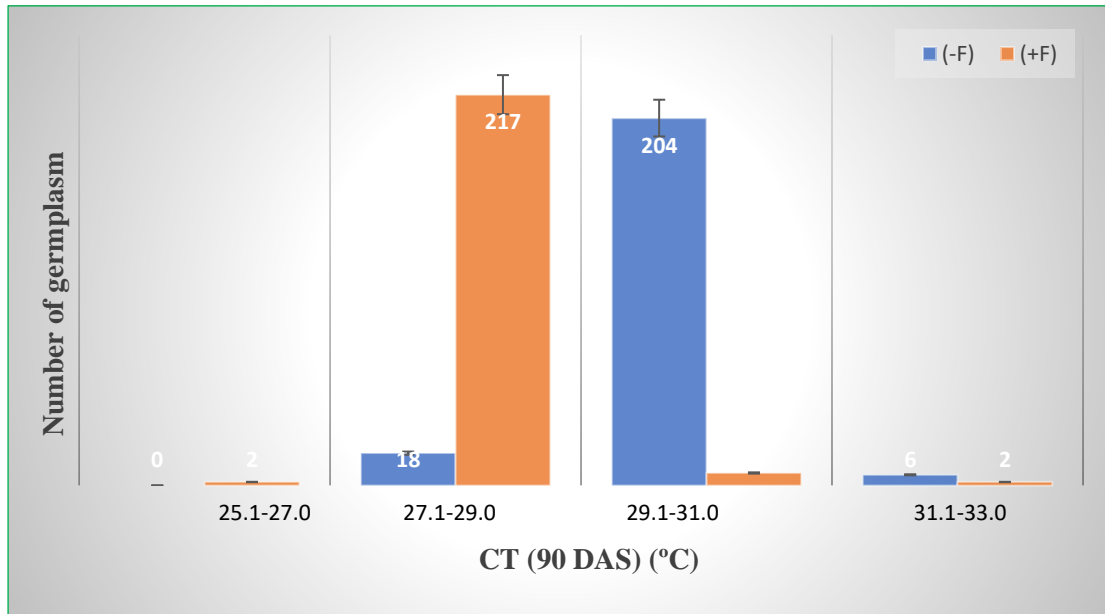


Fig 4.5: Frequency distribution graph for canopy temperature (°C) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 90 DAS

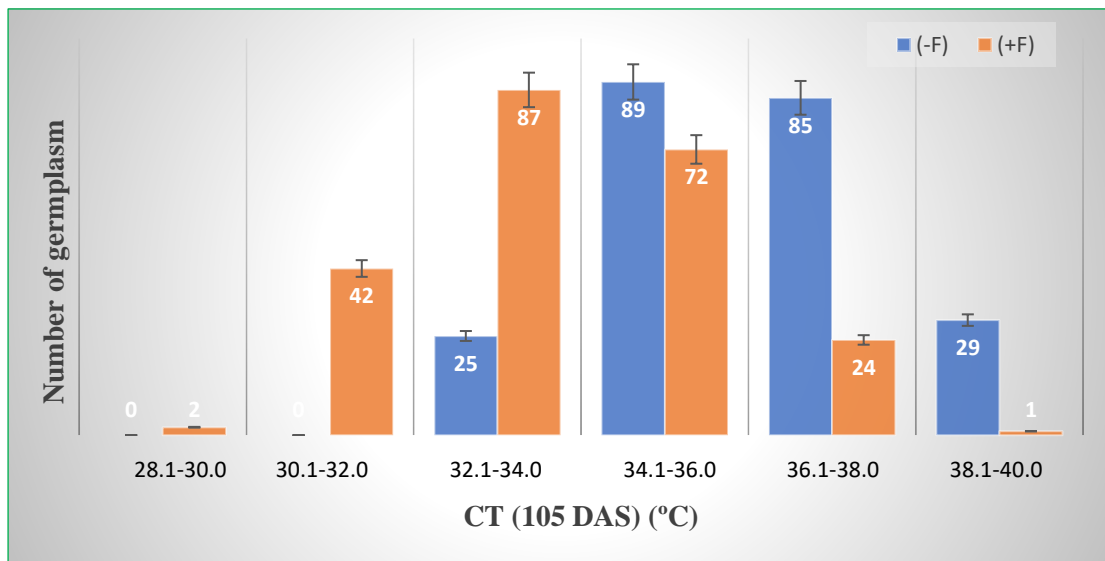


Fig 4.6: Frequency distribution graph for canopy temperature (°C) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at 105 DAS

At 90 days after sowing, maximum CT (°C) was observed in germplasm 58 (31.3) followed by 25 (31.2), 189 (31.0), 40 (31.0), 26 (31.0), 24 (31.0), 29 (30.9), 11 (30.9), 136 (30.9) and 81 (30.9) under -F condition while maximum under +F condition germplasm are 197 (29.7) followed by 196 (29.6) 195 (29.6), 194 (29.6), 193 (29.1), 142 (29.1), 5 (29.1), 135 (29.1), 129 (29.0) and 157 (28.9). However, minimum CT (°C) was observed in germplasm 53

(27.9) followed by 98 (27.9), 68 (28.2), 33 (28.3), 65 (28.3), 50 (28.4), 87 (28.4), 34 (28.4), 54 (28.5) and 74 (28.5) under -F condition while 68 (26.4) followed by 53 (26.7) 21 (27.0), 74 (27.0), 107 (27.0), 98 (27.1), 12 (27.2), 19 (27.2), 20 (27.2) and 50 (27.2) had minimum under +F condition. Maximum number of germplasms showed a range between 29.1 to 31.0°C under -F conditions whereas it was within a range of 27.1 to 29.0°C under +F conditions (Fig.4.5).

At 105 days after sowing, maximum CT (°C) was observed in 117 (39.8) followed by 188 (39.6) 201 (39.1), 157 (39.0), 167 (38.8), 185 (38.8), 120 (38.8), 219 (38.7), 187 (38.7) and 107 (38.7) under -F condition while maximum under +F condition germplasm are 108 (38.1) followed by 107 (37.8), 195 (37.6), 197 (37.3), 194 (37.2), 188 (37.2), 221 (37.1), 186 (37.0), 228 (36.9) and 111 (36.8). However, minimum CT (°C) was observed in germplasm 99 (32.4) followed by 173 (32.6), 22 (32.7), 69 (32.9), 77 (33.0), 2 (33.1), 58 (33.2), 135 (33.3), 34 (33.3) and 67 (33.4) under -F condition while 119 (29.7) followed by 45 (29.8) 29 (30.2), 136 (30.3), 30 (30.4), 73 (30.4), 96 (30.4), 7 (30.5), 139 (30.5) and 124 (30.6) had minimum under +F condition. Maximum number of germplasms showed a range from 34.1 to 36.0°C under -F conditions whereas it was within a range of 32.1 to 34.0°C under +F conditions (Fig. 4.6).

4.1.3 Nitrogen balanced index (NBI)

For germplasm grown under -F condition, NBI values of 25.7 to 85.5 were noted with a mean of 49.4 whereas, in germplasm grown under +F condition range was 36.3 to 127.4 with a mean of 71.0 (Table 4.3).

Table 4.3: Nitrogen balanced index at anthesis in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	49.4	71.0
Range	25.7-85.5	36.3-127.4
CD at 5 %	G = 16.193, F = 1.517, G x F = 22.900	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

NBI at anthesis was noticed maximum in wheat germplasm 21 (85.6) followed by 124 (81.0), 194 (80.9), 120 (78.9), 25 (75.5), 121 (74.4), 195 (73.3), 97 (72.0), 166 (70.9) and 68 (70.8) under -F condition while in germplasm 22 (127.5) followed by 123 (123.5), 167 (118.5), 166 (116.7), 155(113.2), 18(111.7), 38 (109.7), 23 (107.5), 27 (106.1) and 53 (105.9) under +F condition. However minimum NBI was observed in germplasm 180 (25.7) followed by 213 (26.5), 94 (27.3), 179 (29.9), 188 (30.0), 158 (30.2), 37 (30.6), 223 (31.3), 215 (31.9) and 61 (32.0) under -F condition while 180 (36.3) followed by 181 (38.0), 129 (38.3), 179 (38.6), 184 (39.9), 60 (40.4), 178 (41.4), 61 (42.5), 135 (43.4) and 62 (43.9) had minimum NBI under +F condition.

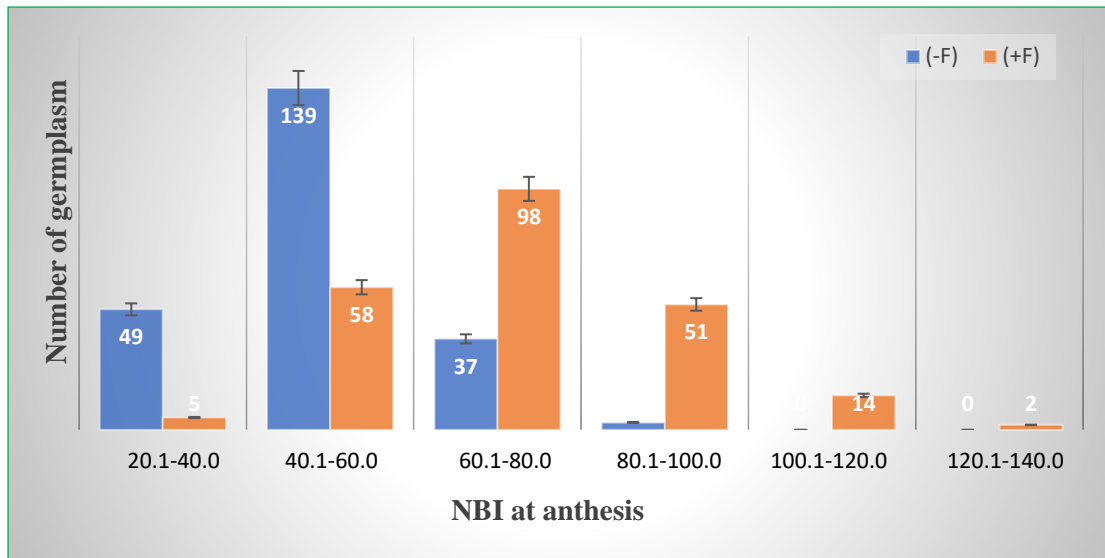


Fig 4.7: Frequency distribution graph for NBI in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at anthesis

At anthesis, maximum number of germplasms showed a range between 40.1 to 60.0 under -F condition whereas it was within a range of 60.1 to 80.0 under +F condition (Fig 4.7).

4.1.4 Chlorophyll index (CHI)

Mean value for CHI under -F condition was noted as 37.1 and values ranges from 21.8 to 53.1 however, with +F condition, a range of 29.0 to 64.8 with a mean of 42.9 was observed (Table 4.4).

Table 4.4: Chlorophyll index at anthesis in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	37.1	42.9
Range	21.8-53.1	29.0-64.8
CD at 5 %	G = 5.532, F = 0.518, G x F = 7.823	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Maximum CHI under -F condition was found in wheat germplasm 166 (53.1) followed by 162 (52.5), 121 (48.0), 117 (48.0), 68 (47.3), 67 (46.2), 6 (46.1), 73 (45.6), 163 (45.5) and 21 (45.4) while under +F condition, maximum CHI was found in wheat germplasm 123 (64.8) followed by 166 (62.3), 162 (57.7), 163 (56.9), 27 (56.8), 74 (55.4), 175 (52.7), 121 (51.8), 117 (51.4) and 43 (51.4). The minimum CHI under -F was found in wheat germplasm 94 (21.8) followed by 180 (24.0), 215 (26.7), 4 (27.1), 179 (27.6), 61 (27.9), 79 (28.2), 213 (28.5), 131 (28.7) and 184 (29.2) while under +F, minimum CHI was in wheat germplasm 180 (29.0) followed by 179 (30.7) 184 (31.3), 178 (31.8), 133 (32.5), 90 (32.7), 60 (32.8), 181 (33.8), 183 (33.8) and 137 (34.1).

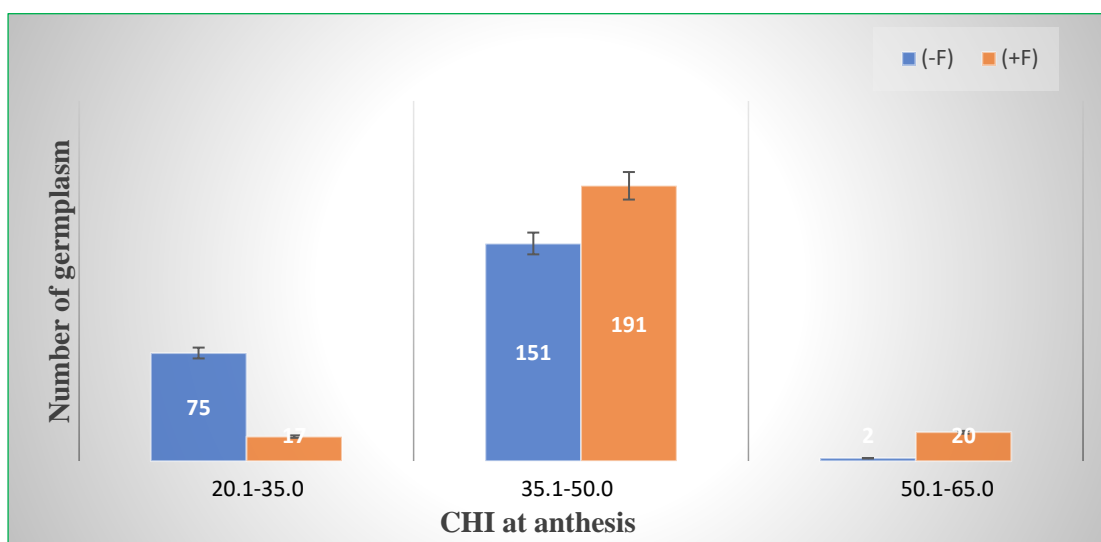


Fig 4.8: Frequency distribution graph for CHI in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at anthesis

At anthesis, maximum number of germplasms showed a range between 35.1 to 50.0 under both -F condition as well as +F condition. (Fig 4.8)

4.1.5 Anthocyanin content

The values were observed under -F condition with a range of 0.14 to 0.24 with a mean of 0.18 whereas under +F condition the mean was 0.14 with a range of 0.10 to 0.19 (Table 4.5).

Table 4.5: Anthocyanin content at anthesis in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	0.18	0.14
Range	0.14-0.24	0.10-0.19
CD at 5 %	G = 0.026, F = 0.002, G x F = 0.037	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Maximum anthocyanin content under -F condition was found in wheat germplasm 213 (0.24) followed by 183 (0.23), 216 (0.23), 188 (0.23), 158 (0.23), 184 (0.22), 221 (0.22), 217 (0.22), 186 (0.22) and 215 (0.22) while under +F condition, maximum anthocyanin content was found in wheat germplasm 159 (0.19) followed by 180 (0.18), 223 (0.18), 184 (0.18), 61 (0.17), 169 (0.17), 60 (0.17), 228 (0.17), 179 (0.17) and 29 (0.17). The minimum anthocyanin content under -F was found in wheat germplasm 2 (0.14) followed by 18 (0.14), 25 (0.14), 113 (0.14), 28 (0.14), 17 (0.14), 19 (0.15), 27 (0.15), 26 (0.15) and 16 (0.15) while under +F, minimum anthocyanin content was in wheat germplasm 156 (0.10) followed by 137 (0.11), 120 (0.11), 124 (0.11), 121 (0.11), 123 (0.11), 117 (0.11), 115 (0.12), 118 (0.12) and 155 (0.12)

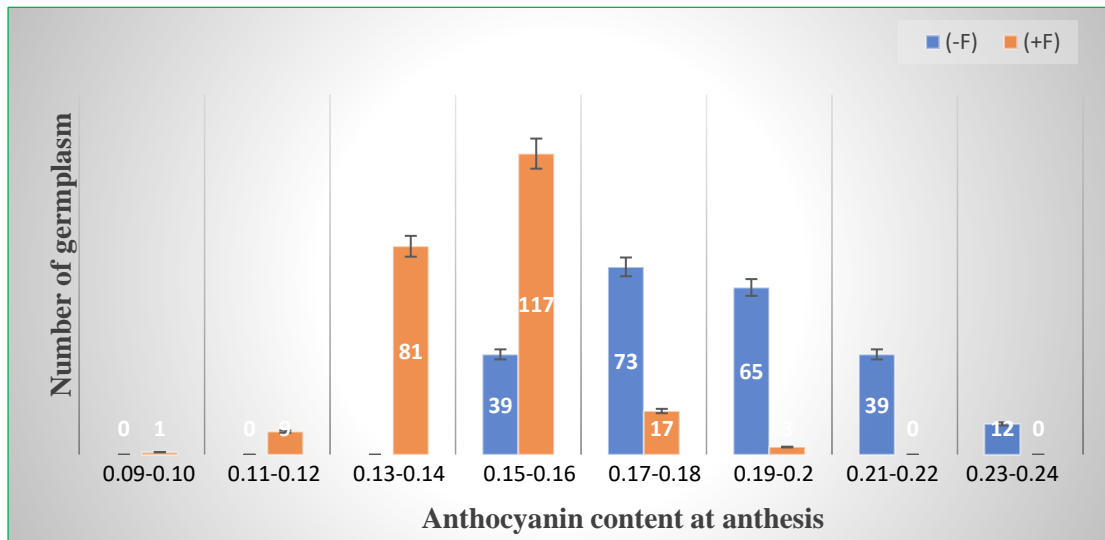


Fig 4.9: Frequency distribution graph for anthocyanin content in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at anthesis

At anthesis, maximum number of germplasm showed a range between 0.17 to 0.18 under -F condition whereas it was within a range of 0.15 to 0.16 under +F condition (Fig 4.9).

4.1.6 Flavonoid content

Under -F condition flavonoids content ranged from 0.53 to 1.13 with mean value of 0.78, however at +F condition with a mean of 0.64, the value ranged from 0.39 to 0.91 (Table 4.6).

Table 4.6: Flavonoid content at anthesis in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	0.78	0.64
Range	0.53-1.13	0.39-0.91
CD at 5 %	G = 0.129, F = 0.012, G x F = 0.182	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Maximum flavonoid content in -F condition was found in wheat germplasm 223 (1.13) followed by 213 (1.09), 209 (1.04), 217 (1.03), 210 (1.01), 99 (1.01), 188 (1.00), 37 (0.99), 129 (0.99) and 139 (0.98) while in +F condition, maximum flavonoid content was found in wheat germplasm 129 (0.91) followed by 181 (0.90), 175 (0.89), 135 (0.86), 62 (0.86), 15 (0.86), 138 (0.85), 58 (0.85), 139 (0.85) and 170 (0.84). The minimum flavonoid content in -F was found in wheat germplasm 21 (0.53) followed by 124 (0.54), 25 (0.54), 22 (0.56), 120 (0.56), 19 (0.58), 194 (0.58), 41 (0.59), 195 (0.59) and 8 (0.60) while in +F, minimum flavonoid content was in wheat germplasm 22 (0.39) followed by 53 (0.39), 36 (0.40), 155 (0.40), 23 (0.41), 187 (0.41), 38 (0.42), 167 (0.43), 64 (0.43) and 35 (0.44).

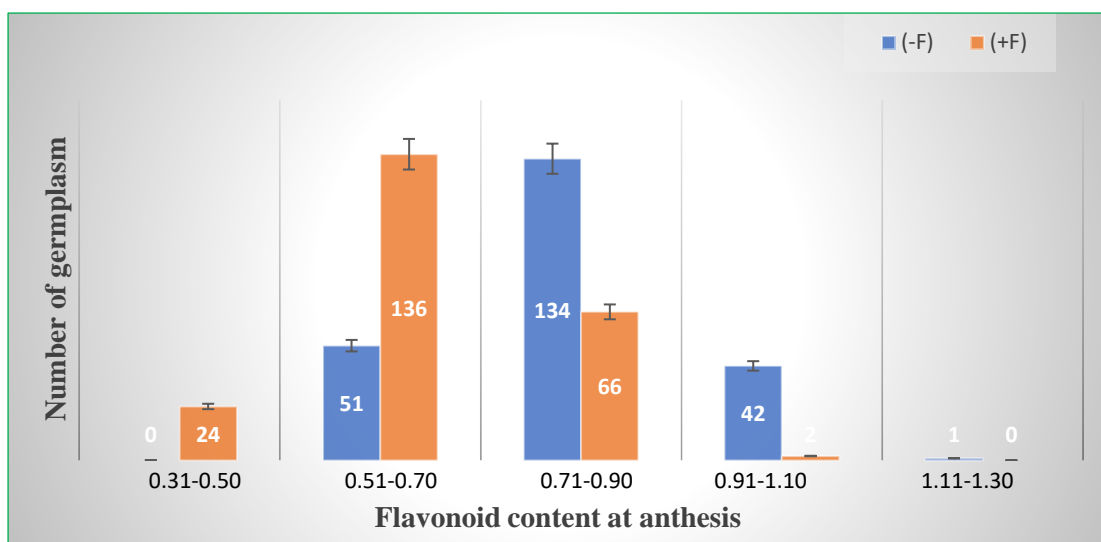


Fig 4.10: Frequency distribution graph for flavonoid content in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at anthesis

At anthesis, maximum number of germplasm showed a range between 0.71 to 0.90 under -F condition whereas it was within a range of 0.51 to 0.70 under +F condition (Fig 4.10).

4.1.7 Osmotic potential (-MPa)

Osmotic potential of germplasm grown under -F condition were with mean value of 1.68 under the range 1.09 to 2.28 whereas the value range for +F condition is 1.26 to 3.66 and with mean 2.15 (Table 4.7).

Table 4.7: Osmotic potential at anthesis in wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	1.68	2.15
Range	1.09-2.28	1.26-3.66
CD at 5 %	G= 0.059, F= 0.005, G x F=0.083	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Maximum OP (-MPa) under -F condition was found in wheat germplasm 216 (2.28) followed by 96 (2.27), 45 (2.25), 54 (2.22), 201 (2.20), 204 (2.19), 105 (2.18), 29 (2.16), 4 (2.16) and 19 (2.14) while under +F condition, maximum OP was found in wheat germplasm 33 (3.66) followed by 95 (3.31), 120 (3.23), 6 (3.22), 4 (3.22), 105 (3.19), 174 (3.14), 98 (3.03), 96 (3.01) and 103 (2.92). The minimum OP under -F was found in wheat germplasm 67 (1.09) followed by 38 (1.12), 92 (1.12), 202 (1.15), 48 (1.17), 149 (1.19), 44 (1.20), 55 (1.20), 31 (1.22) and 53 (1.25) while under +F, minimum OP was in wheat germplasm 53 (1.26) followed by 163 (1.37), 59 (1.44), 69 (1.44), 55 (1.56), 89 (1.58), 48 (1.65), 78 (1.65), 22 (1.67) and 61 (1.69).

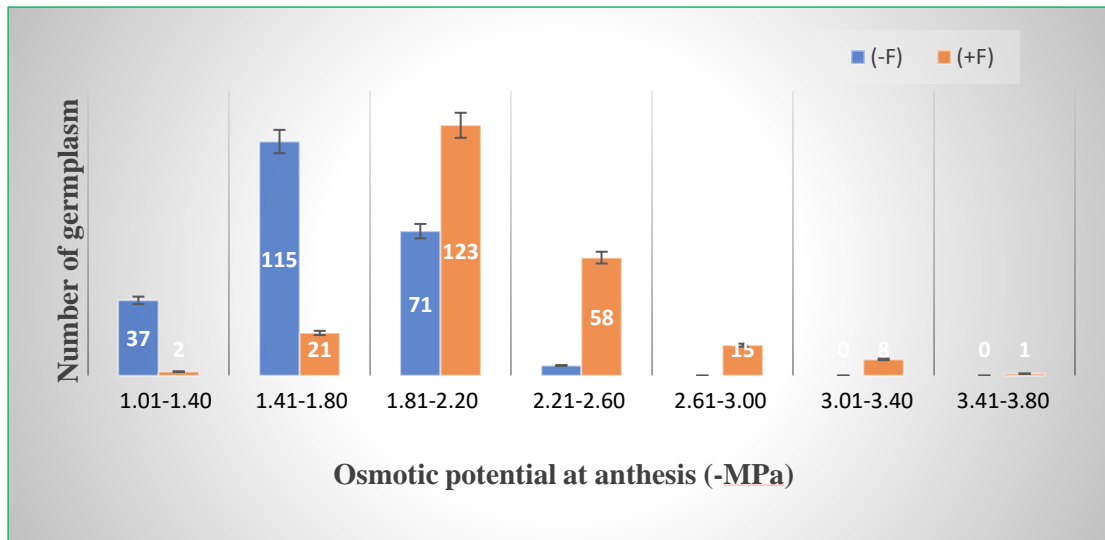


Fig 4.11: Frequency distribution graph for osmotic potential in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition at anthesis

At anthesis, maximum number of germplasms showed a range between 1.41 to 1.80 under -F condition whereas it was within a range of 1.81 to 2.20 under +F condition (Fig 4.11).

4.1.8 Grain growth rate (mg/day) (GGR)

Under -F condition, the mean value obtained for GGR was 1.87 under the value range of 0.86 to 2.38 whereas, for germplasm grown under +F condition, the value comes out to be 1.25 to 2.56 with mean value of 2.06 (Table 4.8).

Table 4.8: Grain growth rate of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	-F	+F
Mean	1.87	2.06
Range	0.86-2.38	1.25-2.56
CD at 5 %	G= 0.058, F= 0.005, G x F =0.081	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Maximum GGR (mg/day) in -F condition was found in wheat germplasm 133 (2.38) followed by 7 (2.32), 37 (2.30), 135 (2.29), 90 (2.27), 29 (2.27), 21 (2.24), 67 (2.22), 89 (2.21) and 103 (2.20) while in +F condition, maximum was found in wheat germplasm 133 (2.56) and 21 (2.51) followed by 37 (2.45), 23 (2.43), 53 (2.42), 135 (2.41), 7 (2.41), 6 (2.41), 90 (2.35) and 29 (2.35). The minimum GGR in -F was found in wheat germplasm 215 (0.86) followed by 144 (0.88), 76 (0.93), 170 (0.98), 159 (0.99), 124 (1.12), 131 (1.21), 129 (1.23), 145 (1.25) and 99 (1.29) while in +F, minimum was in wheat germplasm 144 (1.25) followed by 159 (1.42), 215 (1.54), 76 (1.56), 131 (1.56), 99 (1.59), 145 (1.59), 62 (1.63), 174 (1.68) and 132 (1.68)

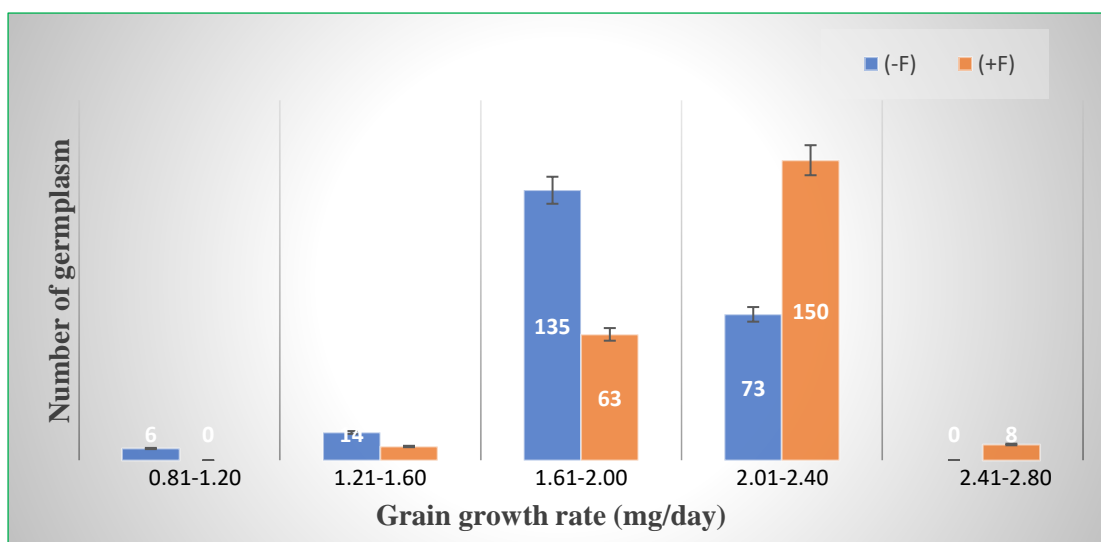


Fig 4.12: Frequency distribution graph for GGR in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

At anthesis, maximum number of germplasms showed a range from 1.61 to 2.00 under -F condition whereas it was within a range of 2.01 to 2.40 under +F condition (Fig.4.12).

4.2 Phenological traits

4.2.1 Days to heading and days to maturity

Number of days to heading was observed with a mean of 78 days in germplasm grown under -F condition with a range of 73 to 84 whereas the mean was 79 days in germplasm grown under +F condition with a range of 76 to 85.

Table 4.9: Days to heading and days to maturity of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	Days to heading		Days to maturity	
	-F	+F	-F	+F
Mean	78	79	111	113
Range	73-84	76-85	109-117	110-120
CD at 5 %	G= 2.397, F= 0.225, G x F = NS		G= NS, F= 0.298, G x F = NS	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Days to maturity was observed with a mean of 111 in germplasm grown under -F condition with a range of 109 to 117 whereas the mean was 113 in germplasm grown under +F condition with a range of 110 to 120 (Table 4.9).

Days to heading was found earliest in wheat germplasm 25 (73) followed by 64 (73), 89 (73), 167 (73), 218 (73), 21 (74), 23 (74), 63 (74), 110 (74) and 113 (74) under -F condition while in germplasm 21 (76) followed by 23 (76), 24 (76), 25 (76), 39 (76), 40 (76), 41 (76), 64 (76), 89 (76) and 107 (76) under +F condition. However, late heading was found in wheat germplasm 171 (84) followed by 210 (83), 169 (83), 213 (82), 206 (82), 152 (82), 136 (82),

222 (81), 219 (81) and 172 (81) under -F condition while in germplasm 221 (85) followed by 171 (85) 118 (85), 210 (84), 175 (84), 172 (84), 117 (84), 104 (84), 170 (83) and 169 (83) under +F condition. Maximum number of germplasms showed a range from 76 to 78 under -F condition whereas it was within a range of 79 to 81 under +F condition (Fig. 4.13).

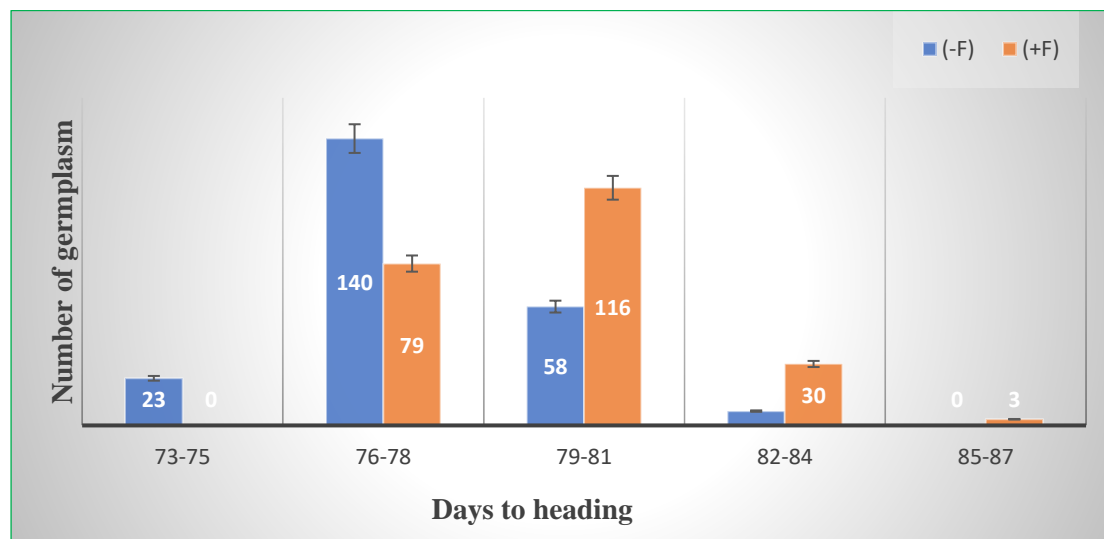


Fig 4.13: Days to heading in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

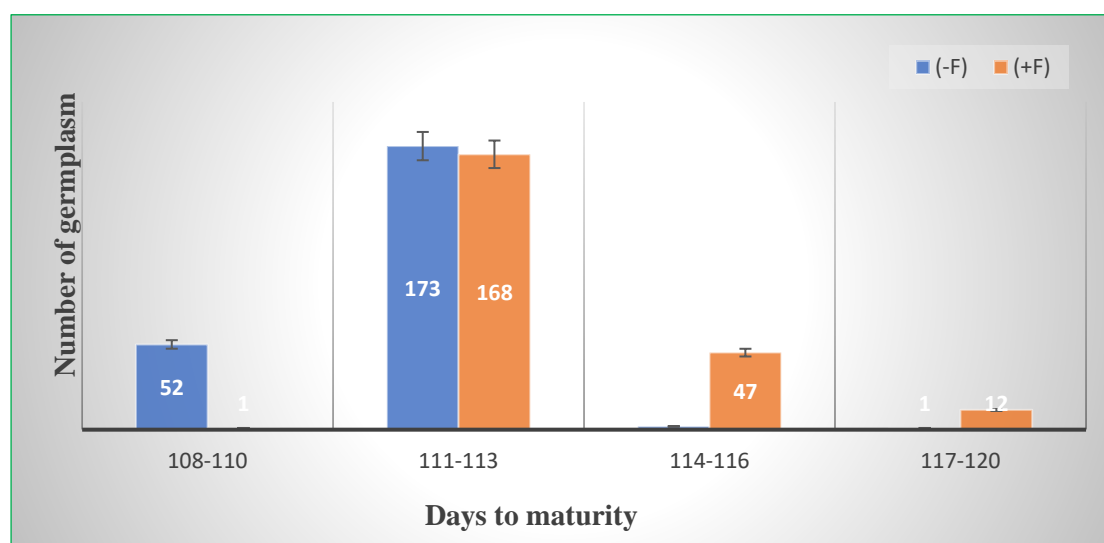


Fig 4.14: Days to maturity in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

Earliest days to maturity was recorded in wheat germplasm 40 (109) followed by 41 (109) 94 (109), 97 (109), 23 (110), 24 (110), 26 (110), 34 (110), 36 (110) and 37 (110) under -F condition while in germplasm 32 (110) followed by 16 (111), 18 (111), 19 (111), 23 (111), 26 (111), 31 (111), 34 (111), 36 (111) and 42 (111) under +F condition. Late days to maturity was found in germplasm 119 (117) followed by 1 (116), 175 (114), 173 (113), 172 (113), 171 (113), 163 (113), 71 (113), 51 (113) and 50 (113) under -F condition while in germplasm 1 (120) followed by 58 (119), 119 (118), 71 (118), 57 (118), 54 (118), 53 (118), 49 (118), 63

(117) and 62 (117) under +F condition. Maximum number of germplasms showed a range from 111 to 113 under -F condition as well as +F condition (Fig. 4.14).

4.3 Yield and its attributes

4.3.1 Plant height (cm) and number of productive tillers/m

The average plant height was observed as 89.99 with a range from 71 to 107 in -F condition and in +F condition, with mean 97.61, a range of 84 to 124 was observed (Table 4.10).

Table 4.10: Plant height and number of productive tillers per meter of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	Plant height (cm)		Number of productive tillers/m	
	-F	+F	-F	+F
Mean	89.99	97.61	77.93	97.74
Range	71-107	84-124	56-114	65-128
CD at 5 %	G= 2.726, F= 0.255, G x F= 3.855		G= 2.696, F= 0.253, G x F= 3.813	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; GxF = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

In case of number of productive tillers/m, the average number of productive tillers per meter in -F condition was observed as 77.93 with a range from 56 to 114 and in +F condition it was observed at 97.74 in a range of 65 to 128 (Table 4.10).

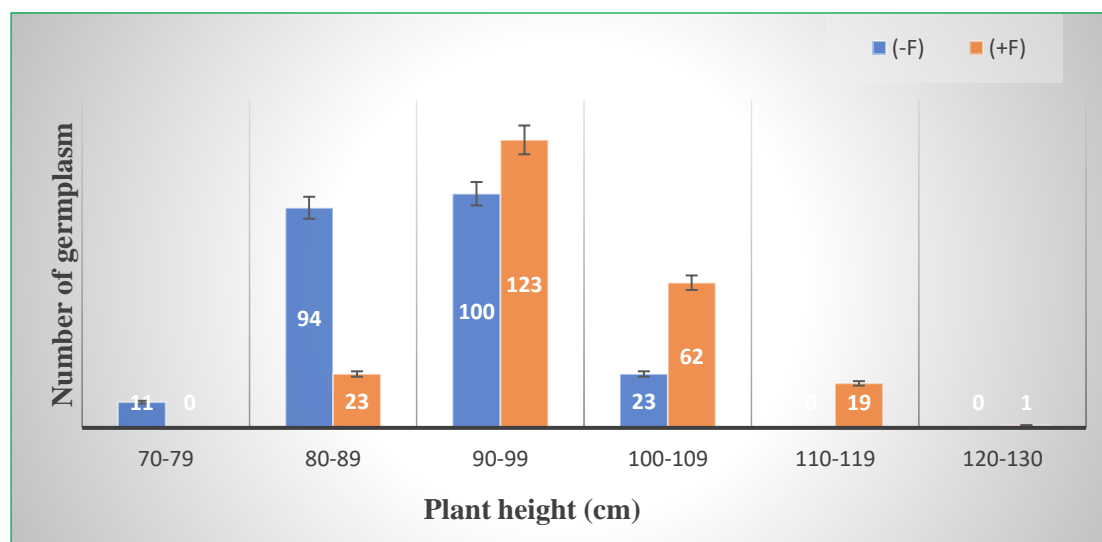


Fig 4.15: Frequency distribution graph for plant height in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

The maximum plant height was observed in wheat germplasm 28 (107 cm) followed by 70 (104 cm), 17 (104 cm), 24 (103 cm), 20 (103 cm), 167 (102 cm), 116 (102 cm), 96 (102 cm), 62 (102 cm) and 21 (102 cm) in -F condition while in +F condition, maximum plant height was found in wheat germplasm 201 (124 cm) followed by 22 (116 cm), 216 (115 cm), 124 (115 cm), 45 (115 cm), 207 (114 cm), 204 (114 cm), 123 (113 cm), 128 (112 cm) and 116 (112 cm).The

minimum plant height was observed in wheat germplasm 185 (71 cm) followed by 80 (72 cm), 89 (72 cm), 97 (72 cm), 81 (75 cm), 112 (75 cm), 3 (77 cm), 14 (78 cm), 186 (78 cm) and 175 (79 cm) in -F condition while in +F condition, minimum plant height was found in wheat germplasm 89 (84 cm) followed by 37 (85 cm), 111 (85 cm), 8 (86 cm), 81 (86 cm), 112 (86 cm), 140 (86 cm), 185 (86 cm), 186 (86 cm) and 50 (87 cm). Maximum number of germplasms showed a range from 90 to 99 under -F condition as well as +F condition (Fig. 4.15).

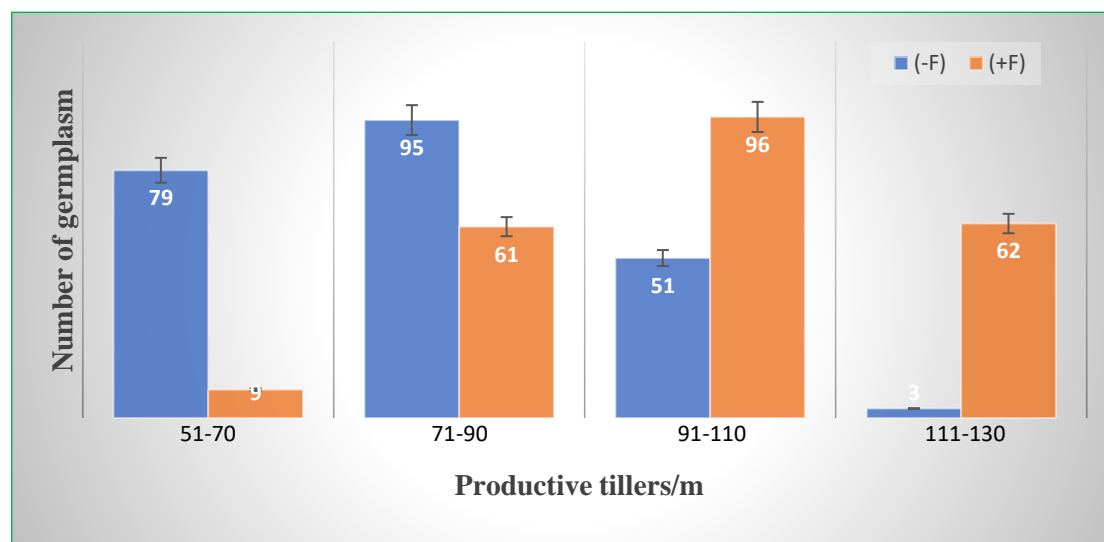


Fig 4.16: Frequency distribution graph for number of productive tillers per meter in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

The highest number of productive tillers per meter was observed in wheat germplasm 105 (114) followed by 164 (111), 104 (110), 110 (107), 167 (105), 70 (105), 218 (105), 206 (104), 225 (103) and 49 (103) in -F condition while in +F condition, maximum number of productive tillers per meter was found in wheat germplasm 168 (128) followed by 105 (128), 70 (127), 109 (126), 65 (125), 164 (125), 27 (125), 218 (124), 104 (124) and 110 (124). The lowest number of productive tillers per meter was observed in wheat germplasm 4 (56) followed by 7 (56), 60 (56), 71 (56), 170 (56), 54 (56), 129 (57), 174 (57), 175 (57) and 31 (57) in -F condition while in +F condition, minimum number of productive tillers per meter was found in wheat germplasm 171 (65) followed by 129 (65), 8 (66), 173 (68), 131 (68), 196 (68), 175 (70), 170 (70), 212 (70) and 85 (71). Maximum number of germplasms showed a range from 71 to 90 under -F condition whereas it was in a range of 91 to 110 under +F condition (Fig. 4.16).

4.3.2 Spike length (cm) and number of spikelets per spike

The average spike length (cm) in -F condition was observed as 9.31 with a range from 6.80 to 13.30 and in +F condition it was observed at 10.84 in a range of 8.20 to 16.50.

Table 4.11: Spike length (cm) and number of spikelets per spike of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	Spike length (cm)		Number of spikelets per spike	
	-F	+F	-F	+F
Mean	9.31	10.84	16.66	18.61
Range	6.80-13.30	8.20-16.50	15-23	15-23
CD at 5 %	G= 0.304, F= 0.028, G x F = 0.430		G= 0.592, F= 0.055, G x F = 0.838	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

In case of number of spikelets per spike, the average number in -F condition was observed as 16.66 with a range between 15 to 23 and in +F condition it was observed at 18.61 in a range of 15 to 23 (Table 4.11).

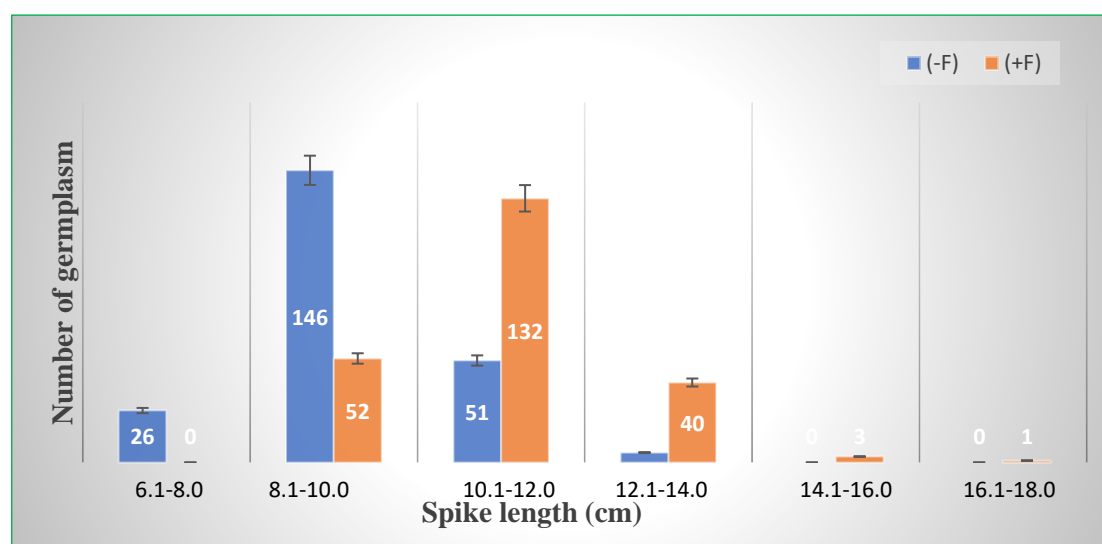


Fig 4.17: Frequency distribution graph for spike length in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

The longest spike was observed in wheat germplasm 166 (13.3 cm) followed by 28 (12.3 cm), 163 (12.2 cm), 29 (12.2 cm), 164 (12.1 cm), 105 (11.7 cm), 207 (11.5 cm), 114 (11.5 cm), 165 (11.3 cm) and 116 (11.3 cm) in -F condition while in +F condition, it was found in wheat germplasm 119 (16.5 cm) followed by 166 (14.5 cm), 207 (14.2 cm), 177 (14.2 cm), 163 (13.9 cm), 116 (13.6 cm), 71 (13.6 cm), 48 (13.6 cm), 209 (13.5 cm) and 1 (13.2 cm). The smallest spike was observed in wheat germplasm 138 (6.8 cm) followed by 7 (7.0 cm), 63 (7.0 cm), 12 (7.2 cm), 44 (7.2 cm), 34 (7.3 cm), 176 (7.3 cm), 183 (7.3 cm), 19 (7.5 cm) and 55 (7.5 cm) in -F condition while in +F condition, it was found in wheat germplasm 14 (8.2 cm) followed by 44 (8.3 cm), 117 (8.4 cm), 118 (8.5 cm), 221 (8.5 cm), 75 (8.6 cm), 179 (8.7 cm), 154 (8.7 cm), 18 (8.8 cm) and 59 (9.0 cm). Maximum number of germplasms showed a range from 8.1 to 10.0 under -F condition whereas it was within a range of 10.1 to 12.0 under +F condition (Fig. 4.17).

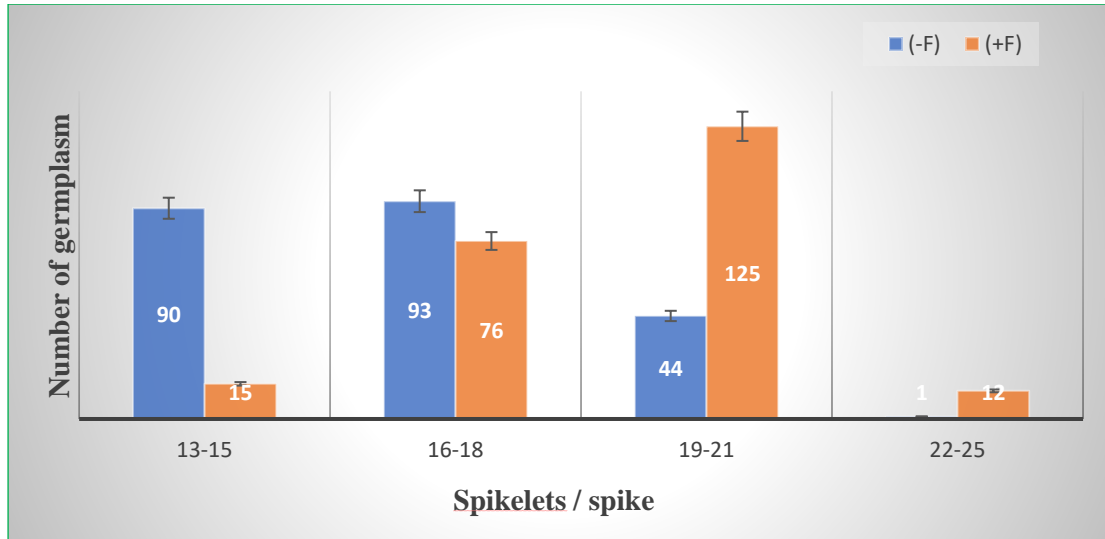


Fig 4.18: Number of spikelets per spike in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

The highest number of spikelets per spike was observed in wheat germplasm 166 (23) followed by 164 (21), 163 (21), 29 (21), 28 (21), 3 (21), 226 (19), 216 (19), 207 (19) and 204 (19) in -F condition while in +F condition, highest number of spikelets per spike was found in wheat germplasm 209 (23) followed by 207 (23), 177 (23), 166 (23), 165 (23), 163 (23), 119 (23), 116 (23), 115 (23) and 71 (23). The lowest number of spikelets per spike was observed in wheat germplasm 2 (15) followed by 7 (15), 10 (15), 12 (15), 14 (15), 16 (15), 18 (15), 19 (15), 20 (15) and 21 (15) in -F condition while in +F condition, minimum number of spikelets per spike was found in wheat germplasm 14 (15) followed by 18 (15) 44 (15), 59 (15), 75 (15), 82 (15), 88 (15), 117 (15), 118 (15) and 148 (15). Maximum number of germplasms showed a range from 16 to 18 under -F condition while it was in a range of 19 to 21 under +F condition. (Fig. 4.18).

4.3.3 Number of grains per spike, grain weight (g/spike) and thousand grain weight (g)

Number of grains/spike was ranged from 29.0 to 64.0 with an average of 42.32 and 33.0 to 79.0 with an average of 51.25 under -F and +F conditions respectively. Grain weight per spike ranged from 0.60 to 2.68 with an average of 1.71 and 1.39 to 3.74 with an average of 2.31 under -F and +F conditions respectively.

Thousand grain weight (g) ranged from 18.60 to 49.80 with an average of 40.23 and 35.20 to 56.20 with an average of 45.15 under -F and +F conditions respectively (Table 4.12).

Maximum no. of grains/spike was found in wheat germplasm 166 (64) followed by 32 (63), 165 (58), 95 (58), 84 (58), 69 (58), 204 (56), 163 (56), 198 (55) and 171 (54) under -F condition while in germplasm 166 (79) followed by 209 (76), 119 (73), 163 (72), 165 (71), 115 (71), 123 (68), 103 (66), 207 (66) and 1 (66) under +F condition. However, minimum number of grains/spike was observed in wheat germplasm 138 (29) followed by 10 (30), 175 (30), 21 (31), 104 (31), 182 (31), 25 (32), 43 (32), 44 (32) and 151 (32) under -F condition while in

germplasm 88 (33) followed by 44 (34), 214 (38), 33 (39), 42 (39), 99 (39), 179 (39), 221 (39), 25 (40) and 40 (40) under +F condition. Maximum number of germplasms showed a range from 39 to 48 in -F condition whereas it was within a range of 49 to 58 in +F condition (Fig. 4.19).

Table 4.12: Number of grains per spike, grain weight (g/spike) and thousand grain weight (g) of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	Number of grains/spike		Grain weight/spike (g/spike)		Thousand grain weight (g)	
	-F	+F	-F	+F	-F	+F
Mean	42.32	51.25	1.71	2.31	40.23	45.15
Range	29-64	33-79	0.60-2.68	1.39-3.74	18.60-49.80	35.20-56.20
CD at 5 %	G= 1.395, F= 0.131, G x F = 1.973		G= 0.061, F= 0.006, G x F = 0.087		G= 1.235, F= 0.116, G x F = 1.747	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

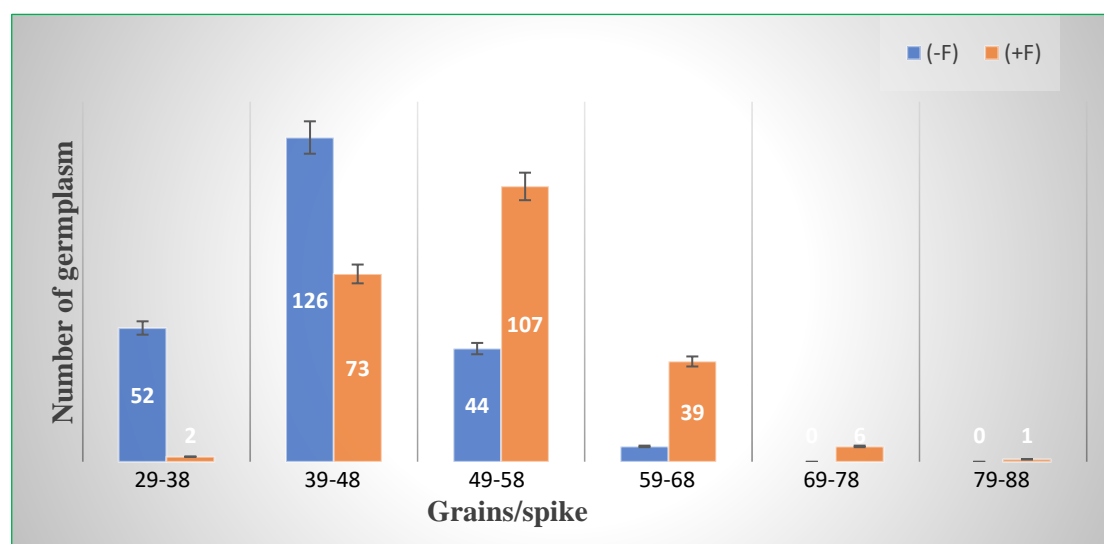


Fig. 4.19: Frequency distribution graph for number of grains per spike in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

Maximum grain weight per spike was found in wheat germplasm 32 (2.68 g) followed by 95 (2.58 g), 116 (2.48 g), 67 (2.47 g), 165 (2.40 g), 89 (2.38 g), 127 (2.36 g), 167 (2.35 g), 113 (2.34 g) and 69 (2.34 g) under -F condition while in germplasm 115 (3.74 g) followed by 166 (3.59 g), 165 (3.49 g), 116 (3.44 g), 209 (3.27 g), 29 (3.26 g), 123 (3.24 g), 103 (3.20 g), 217 (3.11 g) and 133 (3.09 g) under +F condition. However, minimum grain weight per spike was observed in wheat germplasm 215 (0.60 g) followed by 174 (0.82 g), 144 (0.82 g), 99 (0.83 g), 131 (0.84 g), 159 (0.88 g), 76 (0.90 g), 124 (0.91 g), 10 (1.02 g) and 129 (1.03 g) under -F condition while in germplasm 44 (1.39 g) followed by 179 (1.51 g), 33 (1.55 g), 180 (1.69 g), 52 (1.70 g), 18 (1.71 g), 19 (1.72 g), 88 (1.73 g), 10 (1.74 g) and 131 (1.74 g) under +F

condition. Maximum number of germplasm showed a range from 1.31 to 2.10 under -F condition whereas it was in a range of 2.11 to 2.90 under +F condition (Fig. 4.20).

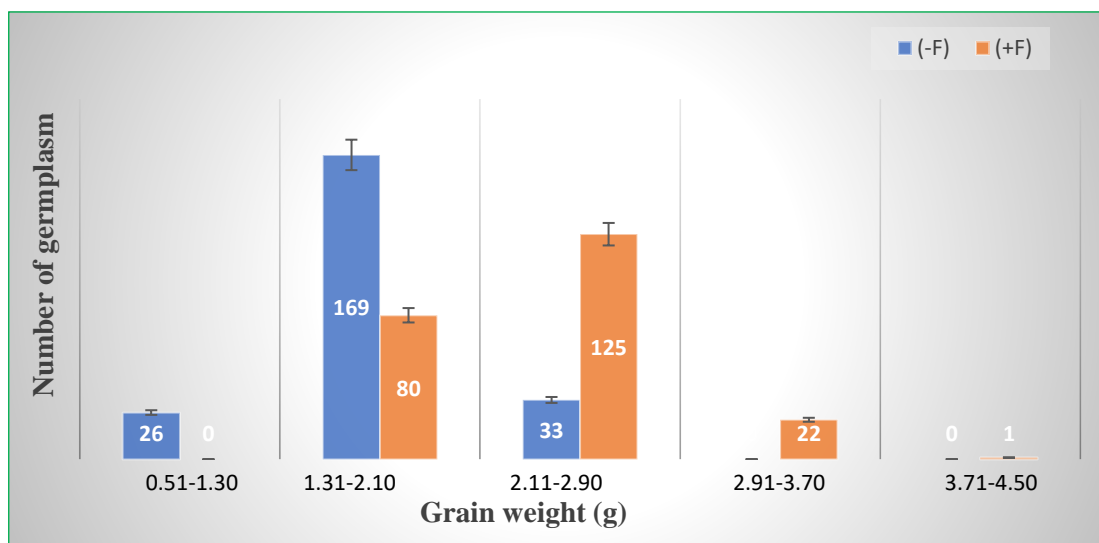


Fig 4.20: Frequency distribution graph for grain weight per spike in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

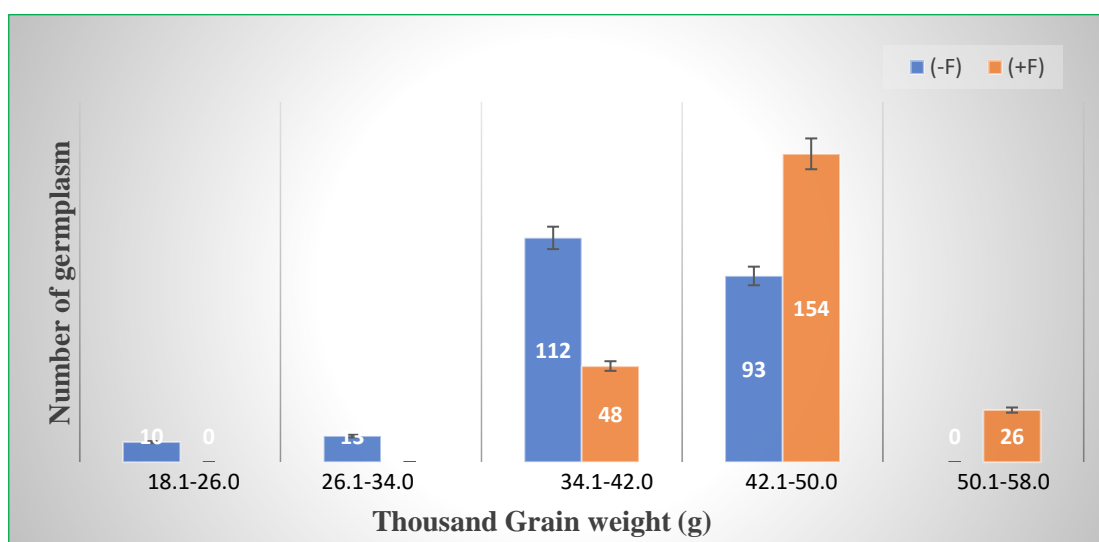


Fig 4.21: Frequency distribution graph for thousand grain weight in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

Highest thousand grain weight was found in wheat germplasm 90 (49.8 g) followed by 116 (49.5 g), 29 (49.5 g), 21 (49.4 g), 134 (49.2 g), 37 (49.1 g), 89 (48.5 g), 127 (48.2 g), 22 (48.1 g) and 156 (48.0 g) under -F condition while in germplasm 133 (56.2 g) followed by 53 (54.6 g), 116 (53.7 g), 117 (53.6 g), 115 (52.7 g), 135 (52.6 g), 88 (52.5 g), 37 (52.2 g), 155 (52.1 g) and 223 (52 g) under +F condition. However, lowest thousand grain weight was observed in wheat germplasm 215 (18.6 g) followed by 124 (19.8 g), 76 (20.5 g), 144 (20.6 g), 159 (22.1 g), 170 (22.3 g), 129 (22.4 g), 99 (23.8 g), 131 (24.6 g) and 174 (25.6 g) under -F condition while in germplasm 144 (35.2 g) followed by 151 (37.4 g), 215 (38.2 g), 227 (38.3 g), 226 (38.4 g), 141 (38.6 g), 178 (38.6 g), 179 (38.7 g), 18 (38.9 g) and 180 (39.4 g) under +F condition.

condition. Most number of germplasms disported a range from 34.1 to 42.0 under -F condition whereas it was within a range of 42.1 to 50.0 under +F condition (Fig. 4.21).

4.3.4 Grain yield (g/m), biomass (g/m) and harvest index (%)

Grain yield (g/m) ranged from 94.5 to 336.0 with an average of 179.3 and 128.5 to 410.0 with an average of 235.0 under -F and +F conditions respectively.

Table 4.13: Grain yield (g/m), biomass (g/m) and harvest index (%) of wheat germplasm lines grown without fertilizer and with recommended dose of fertilizer

Parameters of variability	Grain yield (g/m)		Biomass (g/m)		Harvest index (%)	
	-F	+F	-F	+F	-F	+F
Mean	179.3	235.0	524.69	600.64	34.37	39.35
Range	94-336	128-410	267-931	309-944	24-45	30-48
CD at 5 %	G= 40.589, F= 3.802, G x F = 57.402		G= 54.469, F= 5.289, G x F = 79.860		G= 8.395, F= 0.786, G x F = NS	

C.D. at 5% level of significance; G = Germplasm; F = Fertilizer; G x F = Germplasm x Fertilizer; -F = Without fertilizer; +F = With RDF

Biomass (g/m) ranged from 267.50 to 931.50 with an average of 524.69 and 309 to 944.50 with an average of 600.64 under -F and +F conditions respectively. Harvest index (%) ranged from 24 to 45 with an average of 34.37 and 30 to 48 with an average of 39.35 under -F and +F conditions respectively (Table 4.13).

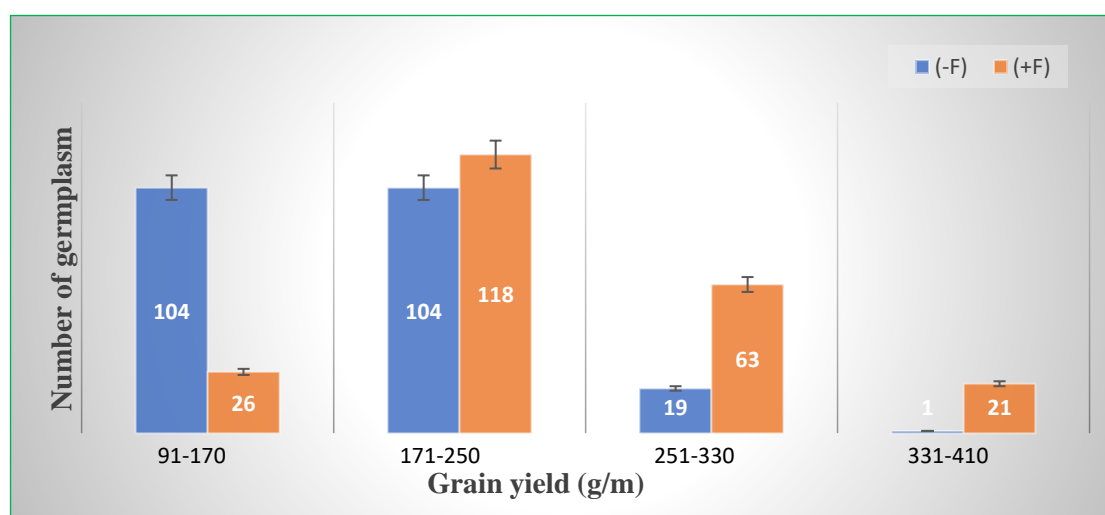


Fig 4.22: Frequency distribution graph for grain yield (g/m) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

Maximum grain yield (g/m) was found in wheat germplasm 53 (336) followed by 49 (310), 56 (300), 43 (286), 23 (284), 48 (280), 21 (278), 42 (273), 51 (270) and 164 (269) under -F condition while in germplasm 49 (410) followed by 34 (385) 220 (377), 64 (374), 53 (370), 48 (361), 52 (350), 45 (348), 27 (343) and 22 (341) under +F condition. However, minimum grain yield was observed in wheat germplasm 140 (95) followed by 139 (95), 175 (98), 16

(100), 188 (100), 152 (110), 11 (113), 213 (113), 1 (115) and 226 (115) under -F condition while in germplasm 175 (129) followed by 139 (143), 171 (143), 162 (145), 131 (145), 185 (147), 196 (150), 136 (150), 137 (150) and 190 (150) under +F condition. Maximum number of germplasms showed a range from 91 to 170 and 171 to 250 under -F condition whereas it was within a range of 171 to 250 under +F condition (Fig. 4.22).

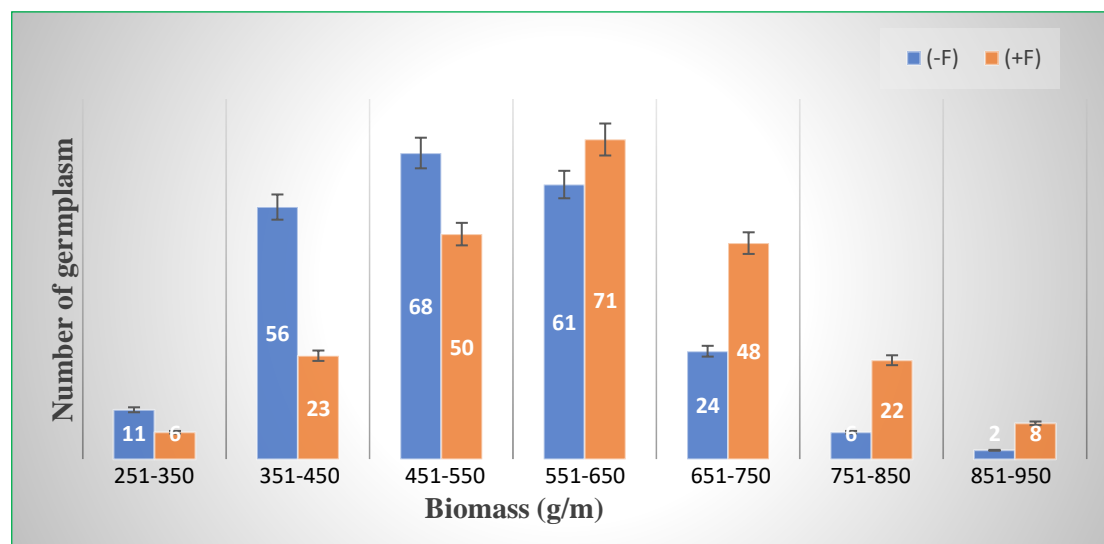


Fig 4.23: Frequency distribution graph for biomass (g/m) in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

Maximum Biomass (g/m) was found in wheat germplasm 53 (932) followed by 56 (876), 49 (816), 61 (795), 42 (781), 18 (776), 27 (766), 70 (762), 69 (743) and 65 (743) under -F condition while in germplasm 53 (945) followed by 220 (942), 49 (925), 61 (914), 64 (896), 27 (886), 127 (865), 34 (860), 70 (846) and 65 (846) under +F condition. However, minimum biomass was observed in wheat germplasm 139 (268) followed by 163 (280), 213 (283), 140 (283), 185 (291), 175 (310), 209 (328), 212 (329), 188 (334) and 127 (339) under -F condition while in germplasm 162 (309) followed by 185 (324), 171 (326), 175 (329), 139 (331), 140 (337), 73 (358), 212 (363), 136 (372) and 213 (377) under +F condition. Maximum number of germplasms showed a range from 451 to 550 under -F condition whereas it was within a range of 551 to 650 under +F condition (Fig. 4.23).

Maximum harvest index was found in wheat germplasm 48 (44.9 %) followed by 52 (44.5 %), 43 (44.2 %), 15 (43.6 %), 44 (43.4 %), 13 (42.9 %), 34 (42.8 %), 212 (42.5 %), 159 (42.4 %) and 40 (42.2 %) under -F condition while in germplasm 13 (48.5 %) followed by 23 (48.4 %), 52 (48.3 %), 11 (48.3 %), 44 (48.2 %), 212 (48.1 %), 112 (48.1 %), 43 (47.8 %), 98 (47.7 %) and 48 (47.7 %) under +F condition. However, minimum harvest index was observed in wheat germplasm 3 (24.1 %) followed by 128 (24.4 %), 131 (24.5 %), 109 (25.9 %), 121 (26.6 %), 107 (27.1 %), 16 (27.3 %), 114 (27.4 %), 61 (27.4 %) and 122 (27.5 %) under -F condition while in germplasm 61 (30.1 %) followed by 16 (30.2 %), 3 (30.7 %), 124 (31.4 %), 193 (31.5 %), 121 (31.7 %), 125 (31.7 %), 128 (31.9 %), 143 (32.0 %) and 142 (32.1 %) under

+F condition. The greatest number of germplasms dispersed a range from 30.1 to 38.0 under -F condition as well as in +F condition (Fig. 4.24).

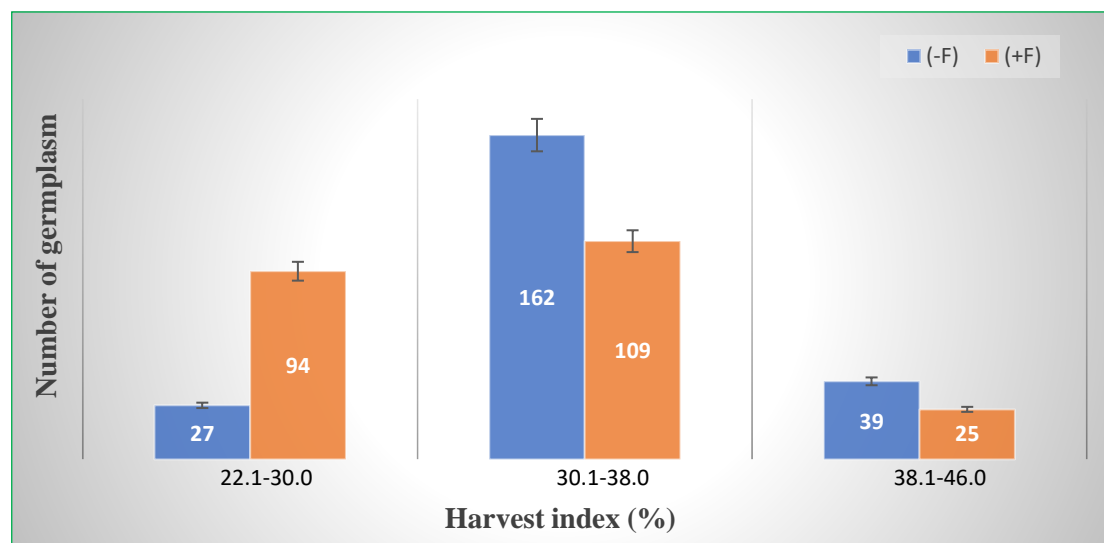


Fig 4.24: Frequency distribution graph for harvest index in wheat germplasm under without fertilizer and with recommended dose of fertilizer condition

4.3.7 Correlation analysis

Table 4.14 and 4.15 represents the correlation between grain yield and physiological traits of wheat germplasm grown under without fertilizer condition (-F) and with fertilizer condition (+F) respectively.

Grain yield had significant positive correlation (Table 4.14) with the physiological traits NDVI 1 (0.460), NDVI 2(0.431), NDVI 3 (0.163) NBI (0.152) and grain growth rate (0.131) while negatively correlated with CT 2 (-0.163), anthocyanin (-0.333), Flavonoids (-0.315) and osmotic potential (-0.203) under -F condition. However, under +F conditions grain yield had significant positive correlation with the traits NDVI 1 (0.322), NDVI 2(0.205), NDVI 3 (0.147), NBI (0.196) and grain growth rate (0.184) while negatively correlated with CT 2 (-0.273), anthocyanin (-0.150), Flavonoids (-0.270), and osmotic potential (-0.022). (Table 4.15).

NBI had significant positive correlation with the traits NDVI 1 (0.261), NDVI 2 (0.182) and CHI (0.762) while negatively correlated with anthocyanin (-0.553) and flavonoids (-0.829) under -F conditions (Table 4.14), while NBI had significant positive correlation as shown in table 4.15 with the traits NDVI 1 (0.303), NDVI 2 (0.164) and CHI (0.693) while negatively correlated with anthocyanin (-0.459) and flavonoids (-0.855) under +F condition.

Table 4.14: Correlation between grain yield and physiological traits of wheat germplasm under without fertilizer

Traits	NDVI 1	NDVI 2	NDVI 3	CT 1	CT 2	CT 3	NBI	CHI	ANTH	FLAV	OP	GGR	GY
NDVI 1	1.000												
NDVI 2	0.574**	1.000											
NDVI 3	0.224**	0.315**	1.000										
CT 1	-0.193**	-0.236**	-0.062	1.000									
CT 2	-0.084	-0.139*	-0.146*	0.263**	1.000								
CT 3	-0.028	-0.079	-0.150*	0.055	0.074	1.000							
NBI	0.261**	0.182**	0.040	0.090	0.129	-0.100	1.000						
CHI	0.054	0.049	0.077	0.090	0.078	-0.076	0.762**	1.000					
ANTH	-0.165*	-0.154*	-0.105	-0.136*	-0.033	0.358**	-0.553**	-0.340**	1.000				
FLAV	-0.298**	-0.207**	-0.001	-0.116	-0.090	0.090	-0.829**	-0.322**	0.606**	1.000			
OP	0.022	-0.052	-0.064	-0.020	0.115	0.103	0.113	0.089	0.177**	-0.054	1.000		
GGR	0.032	0.091	0.040	-0.001	-0.020	-0.013	0.117	0.079	-0.230**	-0.123	0.003	1.000	
GY	0.460*	0.431*	0.163*	-0.106	-0.163*	-0.090	0.152**	-0.075	-0.333**	-0.315**	-0.203*	0.131*	1.000

****Significant at 1 % level of significance; * Significant at 5% level of significance**

NDVI 1: Normalized difference vegetation index at 70 DAS, **NDVI 2:** Normalized difference vegetation index at 90 DAS, **NDVI 3:** Normalized difference vegetation index at 105 DAS, **CT 1:** Canopy temperature at 70 DAS, **CT 2:** Canopy temperature at 90 DAS, **CT 3:** Canopy temperature at 105 DAS, **NBI:** Nitrogen balanced index at anthesis, **CHI:** Chlorophyll index at anthesis, **ANTH:** Anthocyanin content at anthesis, **FLAV:** Flavonoid content at anthesis, **OP:** Osmotic potential at anthesis, **GGR:** Grain growth rate, **GY:** Grain yield per meter

Table 4.15: Correlation between grain yield and physiological traits of wheat germplasm under with recommended dose of fertilizer

Traits	NDVI 1	NDVI 2	NDVI 3	CT 1	CT 2	CT 3	NBI	CHI	ANTH	FLAV	OP	GGR	GY
NDVI 1	1.000												
NDVI 2	0.495**	1.000											
NDVI 3	0.238**	0.334**	1.000										
CT 1	-0.211**	-0.255**	-0.108	1.000									
CT 2	-0.064	-0.069	-0.107	0.163*	1.000								
CT 3	0.086	0.012	-0.049	-0.185**	0.068	1.000							
NBI	0.303**	0.164*	0.085	-0.052	-0.093	-0.022	1.000						
CHI	0.129	0.130*	0.237**	-0.087	-0.052	-0.118	0.693**	1.000					
ANTH	-0.019	-0.062	-0.122	0.048	0.060	0.182**	-0.459**	-0.477**	1.000				
FLAV	-0.293**	-0.117	0.065	0.015	0.091	-0.055	-0.855**	-0.283**	0.336**	1.000			
OP	-0.125	0.004	0.007	0.091	-0.074	-0.130*	-0.023	-0.042	0.012	-0.054	1.000		
GGR	-0.022	-0.032	-0.001	0.052	-0.209**	-0.116	0.227**	0.131*	-0.250**	-0.225**	0.020	1.000	
GY	0.322*	0.205*	0.147*	-0.004	-0.273*	0.002	0.196**	-0.060	-0.150*	-0.270**	-0.022*	0.184*	1.000

****Significant at 1 % level of significance; * Significant at 5% level of significance**

NDVI 1: Normalized difference vegetation index at 70 DAS , **NDVI 2:** Normalized difference vegetation index at 90 DAS, **NDVI 3:** Normalized difference vegetation index at 105 DAS, **CT 1:** Canopy temperature at 70 DAS, **CT 2:** Canopy temperature at 90 DAS, **CT 3:** Canopy temperature at 105 DAS, **NBI:** Nitrogen balanced index at anthesis, **CHI:** Chlorophyll index at anthesis, **ANTH:** Anthocyanin content at anthesis, **FLAV:** Flavonoid content at anthesis, **OP:** Osmotic potential at anthesis, **GGR:** Grain growth rate, **GY:** Grain yield per meter

Cereal grain yield has increased multifold since the green revolution; however, inadequate supply of recommended dose of fertilizer in soil often leads to poor nutrient quality of grain. In addition, wheat is rich in anti-nutritional compounds such as phytin or phenolic compounds that reduce biological availability of essential nutrients to human digestive tract (Welch and Graham, 2004). With the help of new biotechnological tools, the development of superior wheat varieties having improved nutrient content and tolerance to biotic and abiotic stress and high grain yield are possible.

The findings obtained in the present investigation entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” have been discussed below under appropriate headings in response to fertilizer application:

5.1 Physiological parameters influenced by fertilizer application

5.2 Morphological and Phenological attributes in response to fertilization

5.3 Yield and its components affected by fertilizer application

5.4 Character association

5.1 Physiological parameters influenced by fertilizer application

Normalized difference vegetation index (NDVI) shows the availability of nitrogen to the plant and eventually the photosynthetic capacity. It is associated with yield and biomass production (Govaerts *et al.*, 2007). Larger NDVI values are associated with greater number of grains per spike, harvest index and grain yield (Pradhan *et al.*, 2020). The present investigation also shares similar findings. NDVI was found to be highest under +F condition in all the germplasm compared with – F condition (Table 4.1). At 70 DAS maximum NDVI was observed in germplasm 22 (0.79) in -F condition and 119 (0.83) in +F condition. At 90 days after sowing maximum NDVI was observed in 53 and 38 (0.61) in -F and 206 (0.70) in +F condition. At 105 days after sowing maximum NDVI was observed in 71 (0.31) and 54 (0.40) under -F and +F conditions respectively. Higher NDVI values ensure high biomass, photosynthesis and growth rate (Sharma *et al.*, 2018). Vian *et al.* (2018) found that there is a significant association of NDVI with shoot biomass and the amount of accumulated Nitrogen in shoots at different growth stages. This information can be used for variable rate of nitrogen topdressing fertilization, allowing the adjustment of N dose in different areas in the field.

It was observed that decrease in CTD on application of fertilizers under LS condition in all the wheat varieties (Table 4.2). Sharma *et al.* (2018) observed that CTD decreases as the crop matures because canopy gets hotter which results in low photosynthetic assimilation leading to lower yield. Yildirim *et al.* (2013) suggested that canopy temperature fluctuates

throughout the duration of day with higher mean CT recorded during noon or early afternoon and more reliable than that of late morning and evening. Likewise, Yildirim *et al.* (2009) reported that CT had significant correlation with yield. The responses of CTD in various germplasm were found to be similar under both stress and non-stress conditions. The results of the present investigation suggests that Canopy temperature increases in -F as compared to +F condition favoring high yield in fertilized environment. CT was found to be highest in -F condition at 70DAS, 90 DAS and 105 DAS in and lowest in +F condition at 70, 90 and 120 DAS (Table 4.2). Results are in concurrence by the study conducted by Reynolds *et al.* (1994); Munjal & Rana, (2003); Gutierrez *et al.* (2010); Pinto *et al.* (2010) who found that cooler canopy favors good yield. Aberkane *et al.* (2021) observed that as the crop matures, the CT value goes on increasing because canopy gets warmer and results in lower photosynthetic assimilation which leads to lower yield.

In the present investigation, there was a decline in Nitrogen balanced index and chlorophyll index in plants grown under control condition (-F) as compared to fertilized condition (+F) (Table 4.3 and 4.4). Crops experienced a shortage of Nitrogen in the soil which ultimately led to decline in plant Nitrogen status and henceforth the chlorophyll index. These results are in accordance with Kaniszewski *et al.* (2021) where they found that leaf Nitrogen content was positively correlated to the Chlorophyll and NBI indices under varied nitrogen fertilizer rates. They suggested that NBI can be a valuable innovative tool for the sustainable assessment of the N status in plants. Liu *et al.* (2019) revealed that increasing the amount of Nitrogen fertilizer improves the chlorophyll content in leaves, by enhancing the photosynthetic rate.

Anthocyanin and flavonoids index were found to be higher under unfertilized soil condition (-F) in the present investigation (Table 4.5 and 4.6). This result can be explained by Carbon/Nitrogen balance hypothesis as proposed by Nyugen and Niemeyer, (2008). According to this theory, the concentration of carbon-based secondary metabolites (e.g., terpenes and phenolics) will be inversely proportional to Nitrogen availability. Concentrations of Nitrogen-based secondary metabolites (e.g., alkaloids, nonprotein amino acids, cyanogenic compounds and proteinase inhibitors) are directly correlated with the plant's nitrogen availability. According to Stefanelli *et al.* (2010) Nitrogen fertilization reduces the amount of polyphenols in cereal crops.

Osmotic potential (ψ_s) results from dissolved solutes in cell sap and is proportional to solute concentration and inversely proportional to cell water volume. ψ_s in plants is always negative and decreases as solutes concentrate during plant dehydration. The result of present investigation shows decreased osmotic potential under with fertilized (+F) condition at anthesis (Table 4.7). Decrease in osmotic potential may be due to decrease in soil water potential, thus pointing towards higher or lower osmotic adjustment according to the magnitude of stress. The

results are in agreement with the study conducted by (Avramova *et al.*, 2019), where they reported that addition of salts to water lowers its osmotic potential, resulting in decreased availability of water to roots and thus exposes plants to secondary osmotic stress.

In the present investigation, grain growth rate was found to be pronouncedly increased in plants grown under recommended dose of fertilizer (+F) (Table 4.8). This can be attributed to the sufficient availability of macro nutrients for all metabolic processes and hence results into optimized physiological processes. Results are in agreement with the studies conducted by Rani *et al.* (2018) and Ali *et al.* (2019). Grain growth rate (GGR) at 14 and 28 days after anthesis (DAA) showed positive correlations with grain weight per spike and thousand grain weight (Rani *et al.*, 2018). Ali *et al.* (2019) reported that Potassium at a rate of 80 kg ha⁻¹ showed a pronounced grain growth rate and had resulted in a larger number of grains spike⁻¹ and heavier grains.

5.2 Morphological and Phenological attributes in response to fertilization

Days to heading and maturity was found to be slightly high in with fertilized condition (Table 4.9). This may be due to some genotypic interactions or some other environmental factors. However, several studies have reported delayed flowering under N limited/starvation conditions in several crops *viz Arabidopsis*, *Kalanchoe* and *Lemna* (Yuan *et al.*, 2016). A N-regulated U-shaped flowering response was proposed in *Arabidopsis* by Lin and Tsay (2017). However, to determine whether this kind of response can be generalized to other plants and crops, a wide range of NPK concentrations needs to be tested systematically with a range of species.

In the present investigation, plant height was reported to be significantly high in plants grown under recommended dose of fertilizer (+F) (Table 4.10). Similarly, Malghani *et al.* (2010) indicated that plant height, number of tillers/m², and grain yield rose linearly with consecutive increase in NPK up to a level (175:150:125) compared with control (no fertilizer). Iqtidar *et al.* (2006) found that increasing Nitrogen levels from 50 to 200 kg/ha enhanced plant height, total number of plants/m², number of grains/spike, number of spikes/m², spike weight, and grain production.

5.3 Yield and its components affected by fertilizer application

In the present investigation, number of productive tillers per meter row length, spike length (cm), number of spikelets per spike, number of grains per spike, grain weight (g) per spike, thousand grain weight (g), grain yield (g) per meter, biomass (g) per meter and harvest index (%) was found to be highest with recommended dose of fertilizer (Table 4.10 to 4.13). These results suggest that wheat crop responds positively with the application of fertilizer. Similar results have been observed by many investigators (Abedi *et al.*, 2010; Marino *et al.*, 2009; Noureldin *et al.*, 2013; Alam *et al.*, 2003; Rahim *et al.*, 2010; El-gizawy 2009; Arif *et al.*, 2017; Malghani *et al.*, 2010; Chaure *et al.* (2019); Asghar *et al.*, 2010)

According to Abedi *et al.* (2011), treatments that received more Nitrogen fertilizer generated more grain yield. Marino *et al.* (2009), reported that increasing the Nitrogen rate enhanced hulled and unhulled grain production, biomass accumulation, number of spikes/m², and kernels/m². Higher Nitrogen levels up to 180 kg/ha increased grain yield and other yield components, according to Noureldin *et al.* (2013). Alam *et al.* (2003) showed that the plant height greatly increased with increase in rate of Phosphorus application. Rahim *et al.* (2010) reported that thousand grain weight of wheat increased considerably with increasing Phosphorus treatment to the soil. El-gizawy (2009) concluded that the spikes/m² will rise by increasing Nitrogen and Phosphorus fertilizer application. Arif *et al.* (2017) observed an increase in plant height, fertile tiller number per m², spike length, grain number per spike, thousand grain weight, biomass, and grain yield when Potassium rates were increased. Malghani *et al.* (2010) indicated that plant height, number of tillers/m², number of spikes/m², number of grains/spike, 1000 grain weight and grain yield rose linearly with consecutive increase in NPK up to a level (175:150:125) compared with control. Chaure *et al.* (2019) reported that application of RDF @ 80:40:40 kg ha⁻¹ produced highest grain yield when compared with treatment having no fertilizer. Asghar *et al.* (2010) concluded that grain yield of maize and cereal crops rose with application of NPK fertilizer. It was observed that with increase in nitrogen concentration, more Harvest index was recorded Tesfaye *et al.* (2021).

5.4 Character association

Coefficient of correlation analysis determines the reciprocal relationship between different physiological traits and decides the component characteristics on which selection can be centered for genetic yield improvement. Grain yield is a complex polygenic character, which is greatly influenced by the germplasm through interaction with the environment (G x E). The inclusion of various component traits in a selection scheme is obviously not practicable and therefore, it is important to know the extent and nature of interrelationship between grain yield and physiological traits.

Grain yield had significant positive correlation (Table 4.14) with NDVI 1 (0.460), NDVI 2(0.431), NDVI 3 (0.163) NBI (0.152) and with grain growth rate (0.131) while negatively correlated with CT 2 (-0.163), anthocyanin (-0.333), Flavonoids (-0.315) and osmotic potential (-0.203) under -F condition. However, under +F conditions grain yield had significant positive correlation with the traits NDVI 1 (0.322), NDVI 2(0.205), NDVI 3 (0.147), NBI (0.196) and grain growth rate (0.184) while negatively correlated with CT 2 (-0.273), anthocyanin (-0.150), Flavonoids (-0.270), and osmotic potential (-0.022). (Table 4.15). Similarly, Shehrawat and Kumar (2021) has also observed NDVI exhibited positive association, while canopy temperature exhibited negative association with grain yield as the values of genotypic correlation coefficients and direct path values on grain yield are fairly close to each other. Manjunatha *et al.* (2021) and Aberkane *et al.* (2021) also detected positive association between grain yield and NDVI at

different plant growth stages. Kaniszewski *et al.* (2021) found that leaf nitrogen content was positively correlated to the chlorophyll and NBI indices, but negatively correlated to the flavonoid index, under varied nitrogen fertilizer rates. Stefanelli *et al.*, (2010) also concluded that Nitrogen fertilization reduces the amount of polyphenols in cereal crops.

CHAPTER VI

SUMMARY AND CONCLUSION

The present investigation entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” was aimed at photosynthetic characterization of wheat germplasm in response to fertilizer application and to find correlation between physiological traits with grain yield was conducted at the research area of Wheat and Barley Section of Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar during *rabi* 2020-21. Two hundred twenty-eight lines from CIMMYT, Mexico was used for the experiment and observations were taken at different stages of growth for physiological studies while yield characteristics were recorded at maturity. The plants were raised in field under fertilization (+F) (NPK at 100:40:30 kg ha⁻¹) and without fertilization (-F) condition in randomized block design.

Results showed that various physiological, yield and its attributes got adversely affected under without fertilization in late sown condition which are enlisted below:

- ❖ Out of 228 germplasm, maximum NDVI was observed in germplasm 22 , 23 and 53 at 70 DAS and 53, 38 and 36 at 90 DAS and 71, 52 and 49 at 105 DAS under -F condition while in 119, 53 and 51 at 70 DAS and 206, 109 and 53 at 90 DAS and 54, 53 and 12 at 105 DAS under +F condition , however minimum NDVI was observed in 73, 90 and 1 at 70 DAS and in 73, 59 and 137 at 90 DAS and 6, 13 and 20 at 105 DAS under -F condition while in 73, 1 and 9 at 70 DAS and 137, 141 and 29 at 90 DAS and in 72, 137 and 24 DAS under +F condition.
- ❖ Lowest canopy temperature was observed in germplasm 210, 209 and 213 at 70 DAS and in 53, 98 and 68 at 90 DAS and in 99, 173 and 22 at 105 DAS under -F condition and in 217, 95 and 155 at 70 DAS and in 68, 53 and 21 at 90 DAS and in 119, 45 and 29 at 105 DAS under +F conditions. Highest CT was recorded in 90, 10 and 7 at 70 DAS and in 58, 25 and 189 at 90 DAS and in 117, 188 and 201 at 105 DAS under -F condition while in 142, 189 and 141 at 70 DAS and in 197, 196 and 195 at 90 DAS and in 108, 107 and 195 at 105 DAS under +F condition.
- ❖ Nitrogen balanced index and chlorophyll index were reduced under -F condition as compared to +F condition in all germplasm. Maximum Nitrogen balanced index was observed in 21, 124 and 194 under -F condition while in 22, 123 and 167 under +F condition at anthesis. However, minimum Nitrogen balanced index was observed in 180, 213 and 94 and in 180, 181 and 129 under -F and +F conditions respectively. Maximum chlorophyll index was observed in 166, 162 and 121 under -F condition while in 123, 166 and 162 under +F condition at anthesis. However minimum

chlorophyll content index was observed in 94, 180 and 215 under -F condition while in 180, 179 and 184 under +F condition.

- ❖ Anthocyanin content and flavonoid content were reduced under +F condition as compared to -F condition in all germplasm. Maximum anthocyanin content was observed in 213, 183 and 216 under -F condition while in 159, 180 and 223 under +F condition at anthesis. However, minimum anthocyanin content was observed in 2, 18 and 25 and in 156, 137 and 120 under -F and +F conditions respectively. Maximum flavonoids was observed in 223, 213 and 209 under -F condition while in 129, 181 and 175 under +F condition at anthesis. However minimum flavonoids was observed in 21, 124 and 25 under -F condition while in 22, 53 and 36 under +F condition.
- ❖ The maximum osmotic potential (-MPa) was found in germplasm 216 (2.28), 96 (2.27) and 45 (2.25) under -F condition while in 33 (3.66), 95 (3.31) and 120 (3.23) under +F condition. However minimum osmotic potential was observed in germplasm 67 (1.09), 38 (1.12) and 92 (1.12) and in 53 (1.26), 163 (1.37) and 59 (1.44) under -F and +F conditions respectively.
- ❖ The maximum grain growth rate was found in germplasm 133, 7 and 37 under -F condition while in 133, 21 and 37 under +F condition. However minimum grain growth rate was observed in germplasm 215, 144 and 76 and in 144, 159 and 215 under -F and +F conditions respectively.
- ❖ Early days to heading at 73 days was observed in 25, 64 and 89 under -F condition while it was 76 days in 21, 23 and 24 under +F condition.
- ❖ Late days to maturity was observed in germplasm 119, 1 and 175 at 117, 116 and 175 days respectively under -F condition while in 1, 58 and 119 at 120, 119 and 118 days respectively under +F condition.
- ❖ Maximum plant height was recorded in 28, 70 and 17 under -F condition while in 201, 22 and 216 under +F condition. However minimum plant height was observed in germplasm 185, 80 and 89 and in 89, 37 and 111 under - F and + F conditions respectively.
- ❖ Maximum number of productive tillers per meter row length was recorded in 105, 164 and 104 under -F condition while in 168, 105 and 70 under +F condition. However minimum number of productive tillers per meter row length was observed in germplasm 4, 7 and 60 and in 171, 129 and 8 under - F and + F conditions respectively.
- ❖ Maximum spike length was recorded in 166, 28 and 163 under -F condition while in 119, 166 and 207 under +F condition. However, minimum spike length was observed in germplasm 138, 7 and 63 and in 14, 44 and 117 under - F and + F conditions respectively.

- ❖ Maximum number of spikelets per spike was recorded in 166, 164 and 163 under -F condition while in 209, 207 and 177 under +F condition. However, minimum number of spikelets per spike was observed in germplasm 2, 7 and 10 and in 14, 18 and 44 under – F and + F conditions respectively.
- ❖ Maximum number of grains per spike was recorded in 166, 32 and 165 under -F condition while in 166, 209 and 119 under +F condition. However, minimum number of grains per spike was observed in germplasm 138, 10 and 175 and in 88, 44 and 214 under – F and + F conditions respectively.
- ❖ Maximum grain weight per spike (g/spike) was recorded in 32, 95 and 116 under -F condition while in 115, 166 and 165 under +F condition. However, minimum grain weight per spike was observed in germplasm 215, 174 and 144 and in 44, 179 and 33 under – F and + F conditions respectively.
- ❖ Maximum thousand grain weight (g) was recorded in 90, 116 and 29 under -F condition while in 133, 53 and 116 under +F condition. However, minimum thousand grain weight was observed in germplasm 215, 124 and 76 and in 144, 151 and 215 under – F and + F conditions respectively.
- ❖ Highest grain yield (g/m) was recorded in 53, 49 and 56 under -F condition while in 49, 34 and 220 under +F condition. However, lowest grain yield was observed in germplasm 140, 139 and 175 and in 175, 139 and 171 under – F and + F conditions respectively.
- ❖ Highest biomass (g/m) was recorded in 53, 56 and 49 under -F condition while in 53, 220 and 49 under +F condition. However, lowest biomass was observed in germplasm 139, 163 and 213 and in 162, 185 and 171 under – F and + F conditions respectively.
- ❖ Maximum harvest index (%) was recorded in 48, 52 and 43 under -F condition while in 13, 23 and 52 under +F condition. However, minimum harvest index was observed in germplasm 3, 128 and 131 and in 6, 16 and 3 under – F and + F conditions respectively.
- ❖ Highly significant positive correlation between grain yield and physiological traits was observed viz., NDVI, NBI and GGR while canopy temperature, flavonoids, anthocyanin and osmotic potential showed negative correlation under both the conditions (Table 4.14 and 4.15)
- ❖ Among physiological traits NBI showed negative correlation with canopy temperature, anthocyanin and flavonoids while positive correlation with chlorophyll index in both conditions.
- ❖ Canopy temperature showed positive correlation with anthocyanin under both conditions.

Conclusion

Germplasm 21, 44, 68, 159 and 206 performed better under -F condition while germplasm 11, 52, 140, 166 and 220 performed better under +F condition in terms of having higher NDVI, Nitrogen balanced index, chlorophyll index, grain growth rate, biomass, yield and its attributes. The study revealed that the impact of fertilization on crop growth is consistent irrespective of the germplasm. However, some germplasm behaved differentially owing to their inherent potential of nutrient use efficiency and the selected germplasm identified with higher physiological and nutrient use efficient traits may be utilized in conventional breeding programs to better exploit the constrained ecosystem. Hence there should be study on the impact of NPK doses on the nutrient mobilization pattern in different germplasm for their better uptake and utilization in the plant system. During the course of study high temperature was experienced in March and April with a peak of 34 (31st March) and 42°C (30th April) respectively. In relation to high temperature, germplasm 53 (336 g/m), 99 (155 g/m) and 210 (148 g/m) exhibited high temperature tolerance under -F condition while germplasm 68 (238 g/m), 119 (200 g/m) and 217 (276 g/m) exhibited high temperature tolerance under +F condition.

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ANNEXURE I

List of wheat germplasm used for the study

Germplasm no.	Germplasm name
1	DOY1/AE.SQUARROSA (488)//BAJ #1/3/SUP152
2	DOY1/AE.SQUARROSA (488)//BAJ #1/3/SUP152
3	DOY1/AE.SQUARROSA (488)//BAJ #1/3/SUP152
4	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
5	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
6	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
7	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
8	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
9	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
10	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
11	DVERD_2/AE.SQUARROSA (333)//BAJ #1/3/SUP152
12	D67.2/PARANA 66.270//AE.SQUARROSA (677)/3/BAJ #1/4/SUP152
13	D67.2/PARANA 66.270//AE.SQUARROSA (677)/3/BAJ #1/4/SUP152
14	GARZA/BOY//AE.SQUARROSA (695)/3/BAJ #1/4/SUP152
15	IG 42134/BAJ #1//SUP152
16	H-1624/BAJ #1//SUP152
17	H-1624/BAJ #1//SUP152
18	H-1624/BAJ #1//SUP152
19	H-1624/BAJ #1//SUP152
20	H-1624/BAJ #1//SUP152
21	H-1624/BAJ #1//SUP152
22	INDIA-101/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
23	INDIA-101/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
24	INDIA-101/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
25	H-1311/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
26	H-1311/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
27	H-1311/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI
28	H-1311/3/FRET2*2//SHAMA//KACHU/4/HUW234+LR34/PRINIA*2//KIRITATI

29	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (390)/7/SHA7/VEE#5/5/VEE#8// JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/PARUS//PARUS/8/CNDO/R143
30	INDIA- 223/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/PA RUS/ /PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5 /PICUS/6/TROST/7/TACUPETO F2001
31	INDIA- 223/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/PA RUS/ /PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/ WEAVER/ 5/PICUS/6/TROST/7/TACUPETO F2001
32	INDIA- 223/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/ PARUS//PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/ WEAVER /5/PICUS/6/TROST/7/TACUPETO F2001
33	CHIH95.4.6/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SK AUZ/PARUS//PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4 /WEAVER/ 5/PICUS/6/TROST/7/TACUPETO F2001
34	CHIH95.4.6/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SK AUZ/PARUS//PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/ WEAVER/ 5/PICUS/6/TROST/7/TACUPETO F2001
35	CHIH95.4.6/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SK AUZ/PARUS//PARUS/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/ 5/PICUS/6/TROST/7/TACUPETO F2001
36	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/ 5/PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN /CUPE//SW89.3064/5/KIRITATI
37	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER /5/PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/PASTOR /4/MILAN/ CUPE//SW89.3064/5/KIRITATI
38	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5 /PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/PASTOR/4 /MILAN/ CUPE//SW89.3064/5/KIRITATI
39	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5 /PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN/ CUPE//SW89.3064/5/KIRITATI
40	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5 /PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/PASTOR/4/ MILAN/ CUPE//SW89.3064/5/KIRITATI
41	H-1357/8/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5 /PICUS/6/TROST/7/TACUPETO F2001/9/KAUZ//ALTAR 84/AOS/3/ PASTOR/4/ MILAN/ CUPE//SW89.3064/5/KIRITATI
42	IG 42152/6/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064/5/ KIRITATI/ 7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
43	DOY1/AE.SQUARROSA (447)/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/ NELOKI
44	CETA/AE.SQUARROSA(391)/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/R OLF07/5/ NELOKI
45	IG 41489/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI

46	IG 41489/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
47	IG 41505/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
48	IG 41505/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
49	IG 41505/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
50	IG 122145/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
51	IG 122145/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
52	IG 122146/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
53	IG 122146/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
54	IG 122193/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
55	IG 122193/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
56	IG 122193/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
57	IG 122196/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
58	IG 122196/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
59	IG 122795/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
60	68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SUARROSA (890)/6/NELOKI/7/ATTILA*2/PBW65//MURGA
61	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
62	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
63	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
64	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
65	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
66	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
67	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
68	H-1546/NELOKI/3/ATTILA*2/PBW65//MURGA
69	H-1694/NELOKI/3/ATTILA*2/PBW65//MURGA
70	H-1694/NELOKI/3/ATTILA*2/PBW65//MURGA
71	H-1694/NELOKI/3/ATTILA*2/PBW65//MURGA
72	H-1694/NELOKI/3/ATTILA*2/PBW65//MURGA
73	H-1694/NELOKI/3/ATTILA*2/PBW65//MURGA
74	H-1699/NELOKI/3/ATTILA*2/PBW65//MURGA
75	H-1699/NELOKI/3/ATTILA*2/PBW65//MURGA
76	H-1699/NELOKI/3/ATTILA*2/PBW65//MURGA
77	IG 131672/3/ATTILA*2/PBW65//MURGA/4/BORL14
78	IG 131672/3/ATTILA*2/PBW65//MURGA/4/BORL14
79	IG 131672/3/ATTILA*2/PBW65//MURGA/4/BORL14
80	INDIA-38/3/ATTILA*2/PBW65//MURGA/4/BORL14
81	INDIA-38/3/ATTILA*2/PBW65//MURGA/4/BORL14

82	INDIA-38/3/ATTILA*2/PBW65//MURGA/4/BORL14
83	INDIA-38/3/ATTILA*2/PBW65//MURGA/4/BORL14
84	INDIA-50/3/ATTILA*2/PBW65//MURGA/4/BORL14
85	INDIA-50/3/ATTILA*2/PBW65//MURGA/4/BORL14
86	INDIA-50/3/ATTILA*2/PBW65//MURGA/4/BORL14
87	INDIA-50/3/ATTILA*2/PBW65//MURGA/4/BORL14
88	TXL92.8.1/3/ATTILA*2/PBW65//MURGA/4/BORL14
89	LOCAL RED/AE.SQUARROSA (223)//BORL14/3/COPIO
90	LOCAL RED/AE.SQUARROSA (223)//BORL14/3/COPIO
91	LOCAL RED/AE.SQUARROSA (223)//BORL14/3/COPIO
92	LOCAL RED/AE.SQUARROSA (223)//BORL14/3/COPIO
93	LOCAL RED/AE.SQUARROSA (223)//BORL14/3/COPIO
94	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (628)/5/BORL14/6/COPIO
95	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (628)/5/BORL14/6/COPIO
96	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (628)/5/BORL14/6/COPIO
97	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (628)/5/BORL14/6/COPIO
98	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (628)/5/BORL14/6/COPIO
99	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
100	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
101	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
102	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
103	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
104	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
105	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
106	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
107	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
108	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO

109	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
110	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
111	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO
112	D67.2/PARANA 66.270//AE.SQUARROSA (1085)/3/BORL14/4/COPIO
113	D67.2/PARANA 66.270//AE.SQUARROSA (1085)/3/BORL14/4/COPIO
114	IWA8612416/BORL14//COPIO
115	IWA8612416/BORL14//COPIO
116	IWA8612416/BORL14//COPIO
117	IWA8612416/BORL14//COPIO
118	IWA8611400/BORL14//COPIO
119	IWA8611400/BORL14//COPIO
120	IWA8611400/BORL14//COPIO
121	T.DICOCCON PI94624/AE.SQUARROSA (454)//COPIO/3/KACHU #1/KIRITATI//KACHU
122	T.DICOCCON PI94624/AE.SQUARROSA (454)//COPIO/3/KACHU #1/KIRITATI//KACHU
123	T.DICOCCON PI94624/AE.SQUARROSA (454)//COPIO/3/KACHU #1/KIRITATI//KACHU
124	T.DICOCCON PI94625/AE.SQUARROSA (372)//COPIO/3/KACHU #1/KIRITATI//KACHU
125	T.DICOCCON PI94625/AE.SQUARROSA (372)//COPIO/3/KACHU #1/KIRITATI//KACHU
126	T.DICOCCON PI94625/AE.SQUARROSA (372)//COPIO/3/KACHU #1/KIRITATI//KACHU
127	IG 41620/COPIO/3/KACHU #1/KIRITATI//KACHU
128	IG 41620/COPIO/3/KACHU #1/KIRITATI//KACHU
129	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
130	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
131	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
132	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
133	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
134	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
135	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
136	PERSIA-7/COPIO/3/KACHU #1/KIRITATI//KACHU
137	PERSIA-21/COPIO/3/KACHU #1/KIRITATI//KACHU
138	PERSIA-21/COPIO/3/KACHU #1/KIRITATI//KACHU
139	PERSIA-21/COPIO/3/KACHU #1/KIRITATI//KACHU

140	PERSIA-21/COPIO/3/KACHU #1/KIRITATI//KACHU
141	CETA/AE.SQUARROSA (850)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA *2//FRTL/PIFED
142	CETA/AE.SQUARROSA (850)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA*2 //FRTL/PIFED
143	CETA/AE.SQUARROSA (872)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA*2 //FRTL/PIFED
144	CETA/AE.SQUARROSA (872)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA*2 //FRTL/PIFED
145	CETA/AE.SQUARROSA (895)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA*2 //FRTL/PIFED
146	CETA/AE.SQUARROSA (895)/3/KACHU #1/KIRITATI//KACHU/4/PBW343*2/KUKUNA*2 //FRTL/PIFED
147	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (460)/5/KACHU #1/KIRITATI//KACHU/6/ PBW343*2/KUKUNA*2//FRTL/PIFED
148	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (460)/5/KACHU #1/KIRITATI//KACHU/ 6/PBW343*2/KUKUNA*2//FRTL/PIFED
149	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (460)/5/KACHU #1/KIRITATI//KACHU/ 6/PBW343*2/KUKUNA*2//FRTL/PIFED
150	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (477)/5/KACHU #1/KIRITATI//KACHU/6/ PBW343*2/ KUKUNA*2//FRTL/PIFED
151	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (477)/5/KACHU #1/KIRITATI//KACHU/ 6/PBW343*2/KUKUNA*2//FRTL/PIFED
152	YAV79//DACK/RABI/3/SNIPE/4/AE.SQUARROSA (477)/5/KACHU #1/KIRITATI//KACHU/ 6/PBW343*2/KUKUNA*2//FRTL/PIFED
153	GARZA/BOY//AE.SQUARROSA (278)/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
154	GARZA/BOY//AE.SQUARROSA (281)/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
155	DOY1/AE.SQUARROSA (415)/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
156	LOCAL RED/AE.SQUARROSA (220)/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
157	LOCAL RED/AE.SQUARROSA (220)/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
158	JAL95.4.3/VORB//ROLF07
159	H-1491/ROLF07//NAVJ07
160	H-1491/ROLF07//NAVJ07
161	H-1491/ROLF07//NAVJ07
162	H-1491/ROLF07//NAVJ07
163	IG 41243/NAVJ07//KACHU
164	IG 41243/NAVJ07//KACHU
165	H-1601/NAVJ07//KACHU

166	H-1601/NAVJ07//KACHU
167	MEX94.30.10/NAVJ07//KACHU
168	MEX94.30.10/NAVJ07//KACHU
169	ARLIN/AE.SQUARROSA (283)//KACHU/3/BAJ #1
170	ARLIN/AE.SQUARROSA (283)//KACHU/3/BAJ #1
171	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
172	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
173	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
174	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
175	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
176	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
177	CROC_1/AE.SQUARROSA (436)//KACHU/3/BAJ #1
178	CROC_1/AE.SQUARROSA (176)//KACHU/3/BAJ #1
179	CROC_1/AE.SQUARROSA (176)//KACHU/3/BAJ #1
180	CROC_1/AE.SQUARROSA (176)//KACHU/3/BAJ #1
181	GAN/AE.SQUARROSA (206)//KACHU/3/BAJ #1
182	GAN/AE.SQUARROSA (206)//KACHU/3/BAJ #1
183	GAN/AE.SQUARROSA (206)//KACHU/3/BAJ #1
184	GAN/AE.SQUARROSA (206)//KACHU/3/BAJ #1
185	D67.2/PARANA 66.270//AE.SQUARROSA (506)/3/KACHU/4/BAJ #1
186	INDIA-59/KACHU//BAJ #1
187	INDIA-59/KACHU//BAJ #1
188	INDIA-59/KACHU//BAJ #1
189	INDIA-107/KACHU//BAJ #1
190	INDIA-107/KACHU//BAJ #1
191	INDIA-107/KACHU//BAJ #1
192	INDIA-107/KACHU//BAJ #1
193	IG 41474/NAVJ07//KACHU
194	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
195	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
196	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
197	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
198	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
199	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
200	IG 41506/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
201	IG 41735/NAVJ07//KACHU

202	IG 41735/NAVJ07//KACHU
203	IG 41735/NAVJ07//KACHU
204	IG 43238/NAVJ07//KACHU
205	IG 107128/4/PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/5/NELOKI
206	IG 122139/NAVJ07//KACHU
207	IG 122139/NAVJ07//KACHU
208	IG 122627/6/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064/5/KIRITATI/ 7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
209	IG 122627/6/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064/5/KIRITATI /7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
210	IG122627/6/KAUZ//ALTAR84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064 /5/KIRITATI /7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
211	IG122627/6/KAUZ//ALTAR84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064/5 / KIRITATI/ 7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
212	IG 122627/6/KAUZ//ALTAR 84/AOS/3/PASTOR/4/MILAN/CUPE//SW89.3064/5/KIRITATI /7/SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/HEILO
213	IG 122738/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
214	IG 122738/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
215	IG 122740/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
216	IG 122740/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
217	IG 122741/NAVJ07//KACHU
218	IG 122741/NAVJ07//KACHU
219	IG 122741/NAVJ07//KACHU
220	IG 122743/NAVJ07//KACHU
221	PERSIA-88/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
222	PERSIA-88/3/PBW343*2/KUKUNA*2//FRTL/PIFED/4/QUAIU #1
223	IWA 8602098/NAVJ07//KACHU
224	IWA8612134/NAVJ07//KACHU
225	IWA8614378/NAVJ07//KACHU
226	IWA8614378/NAVJ07//KACHU
227	IWA8614378/NAVJ07//KACHU
228	IWA8614378/NAVJ07//KACHU

ANNEXURE II

Table A: Monthly Temperature (°C), Rainfall (mm), Relative Humidity (%) and Sunshine (hrs) during wheat crop season 2020-2021

Month	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)		Sunshine (hrs)
	Max. (°C)	Min. (°C)		M (%)	E (%)	
Dec. 2020	21.5	5	0	93	51	5.9
Jan. 2021	17.4	6	8.9	98	69	3.6
Feb. 2021	25.7	8.1	8.7	97	48	6.8
March 2021	31	13.5	5.6	87	37	6.7
April 2021	36.3	16.2	1	62	21	8.6

ANNEXURE III

ANOVA table for all physiological and yield parameters

Table A: Mean sum of square for NDVI at 70 DAS, 90 DAS and 105 DAS in wheat germplasm over the fertilizer application

Source of variation	df	NDVI		
		70 DAS	90 DAS	105 DAS
Replication	2	0.000	0.000	0.000
Germplasm	227	0.020**	0.013**	0.009**
Fertilizer	1	2.969**	2.491**	1.774**
G*F	227	0.004**	0.004**	0.004**
Error	910	0.000	0.000	0.000

**Significant at 1 % level of significance; NDVI: Normalized Difference Vegetation Index

Table B: Mean sum of square for CT at 70 DAS, 90 DAS and 105 DAS in wheat germplasm over the fertilizer application

Source of variation	df	CT		
		70 DAS	90 DAS	105 DAS
Replication	2	2.003	2.093	0.508
Germplasm	227	2.619**	1.263**	12.808**
Fertilizer	1	425.890**	595.555**	1809.928**
G*F	227	1.075**	0.706**	4.172**
Error	910	0.456	0.513	0.806

**Significant at 1 % level of significance; CT: Canopy Temperature

Table C: Mean sum of square for NBI, CHI, ANTH, FLAV, OP and GGR in wheat germplasm over the fertilizer application

Source of variation	df	NBI	CHI	ANTH	FLAV	OP	GGR
Replication	2	1315.796	32.020	0.054	0.148	0.004	0.002
Germplasm	227	1018.261**	132.315**	0.001**	0.056**	0.397**	0.291**
Fertilizer	1	159702.205**	11568.190**	0.506**	7.044**	77.083**	11.644**
G*F	227	288.814**	30.724**	0.001**	0.017**	0.192**	0.023**
Error	910	204.146	23.825	0.001	0.013	0.003	0.003

**Significant at 1 % level of significance; NBI: Nitrogen balanced index at anthesis, CHI: Chlorophyll index at anthesis, ANTH: Anthocyanin content at anthesis, FLAV: Flavonoid content at anthesis, OP: Osmotic potential at anthesis, GGR: Grain growth rate

Table D: Mean sum of square for DH, DM, PH, NSPS, SL and NPT in wheat germplasm over the fertilizer application

Source of variation	df	DH	DM	PH	NSPS	SL	NPT
Replication	2	8.930	14.729	7.897	2.316	0.311	0.500
Germplasm	227	19.730**	9.203	236.463**	14.679**	6.349**	1190.343**
Fertilizer	1	1016.112**	1173.457**	19834.562**	1289.170**	799.365**	134271.790**
G*F	227	3.886	4.090	52.587**	4.675**	2.046**	132.151**
Error	910	4.474	7.881	5.785	0.273	0.072	5.660

****Significant at 1 % level of significance; DH:** Days to Heading, **DM:** Days to Maturity, **PH:** Plant height, **NSPS:** Number of spikelets per spike, **SL:** Spike Length, **NPT:** Number of Productive Tillers per meter row length

Table E: Mean sum of square for BM, NGS, GW, GY, 1000 GW and HI in wheat germplasm over the fertilizer application

Source of variation	df	BM	NGS	GW	GY	1000 GW	HI
Replication	2	33001.974	0.277	0.004	239.562	0.248	170.319
Germplasm	227	79304.330**	251.774**	0.702**	13845.075**	101.019**	91.161**
Fertilizer	1	1972505.056**	27298.480**	126.134**	1061452.658**	8274.699**	8488.184**
G*F	227	14112.536**	60.382**	0.193**	2516.794**	37.901**	15.354
Error	910	2482.756	1.516	0.003	1282.720	1.188	54.871

****Significant at 1 % level of significance; BM:** Biomass per meter, **NGS:** Number of grains per spike, **GW:** Grain weight per spike, **GY:** Grain yield per meter, **1000 GW:** Thousand grain weight, **HI:** Harvest index

ABSTRACT

Title of Thesis	:	Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition
Full Name of the Degree Holder	:	P S KIRAN
Admission Number	:	2019BS37M
Title of the Degree	:	Master of Science
Name of Discipline	:	Plant Physiology
Name and Address of Major Advisor	:	Dr. Vinod Goyal Assistant scientist Department of Botany and Plant Physiology CCS Haryana Agricultural University Haryana-125 004
Degree Awarding University	:	CCS Haryana Agricultural University Hisar-125 004 (Haryana), India
Year of Award of Degree	:	2021
Major Subject	:	Plant Physiology
Total Number of Pages in Thesis	:	51 + viii + XI
No. of words in abstract	:	335

Key words: Wheat, Fertilizer, Nitrogen balanced index (NBI), Chlorophyll index (CHI), Flavonoids and Anthocyanins

Present investigation was conducted on 228 wheat germplasm lines with unknown nutrient use efficiency obtained from CIMMYT, Mexico through Department of Genetics and Plant Breeding, COA, Hisar for evaluation and photosynthetic characterization under late sown conditions and to find correlation between physiological traits with grain yield with two set of treatments viz. without fertilizer (-F) and with recommended dose of fertilizer (+F) (NPK at 100:40:30 kg ha⁻¹). The experiment was conducted at the Research area of Wheat and Barley Section of Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar during rabi 2020-21. Observations were taken at different stages of growth for physiological studies while yield characteristics were recorded at maturity. The plants were raised in field under fertilization and without fertilization condition under randomized block design.

Under fertilized condition, all germplasm lines showed high vegetation index, Nitrogen balanced index (NBI), Chlorophyll index, Osmotic potential and Grain growth rate. Other than these parameters yield parameters like biomass, grain yield, no. of productive tillers, no. of grains/spike, grain weight/spike, spike length, 1000-grain weight also observed high under fertilized condition. Anthocyanins and flavonoids were found to be high in non-fertilized condition which indicated the presence of stress in the crop. It was found that the physiological parameters were positively correlated with fertilized application. The yield parameters and some physiological parameters showed positive correlation with fertilizer (+F) like NDVI, NBI, and GGR etc. while others were negatively correlated like anthocyanins, flavonoids, osmotic potential, canopy temperature (CT) etc. Germplasm lines 21, 44, 68, 159 and 206 performed better under -F condition while germplasm lines 11, 52, 140, 166 and 220 performed better under +F condition in terms of having higher NDVI, Nitrogen balanced index, chlorophyll index, grain growth rate, biomass, yield and its attributes. The study revealed that the impact of fertilization on crop growth is consistent irrespective of the germplasm. However, some germplasm behaved differentially owing to their inherent potential of nutrient use efficiency and the selected germplasm identified with higher physiological and nutrient use efficient traits may be utilized in conventional breeding programs to better exploit higher NUE efficiency traits.

MAJOR ADVISOR

SIGNATURE OF STUDENT

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Degree	Institution	Year of passing	Aggregate Marks (%)	Subjects
10 th	CBSE	2012	87.40%	Mathematics, Science, Social Science, Malayalam, English
10+2	CBSE	2014	87.00%	Mathematics, Physics, Chemistry, Biology, English
B.Sc. (Hons.) Agriculture	University of Agriculture Sciences, Dharwad	2019	82.90%	Agriculture and allied subjects
M.Sc.	CCS HAU, Hisar	2021	80.60%	Major: Plant physiology Minor: Biochemistry

Co-Curricular Activities:

1. Participated in sports events and few cultural programmes during schooling
2. Received Kerala Film Critics Award for best child artist in 2006

Medals/Honors received:

1. ICAR UG NTS (AIEEA) fellowship during B.Sc. Agriculture
2. ICAR PG (NTS) fellowship during M.Sc. programme.
3. Qualified JAM in biological sciences and biotechnology in 2019

Trainings attended:

Attended an outreach programme conducted by IIRS – ISRO on the topic “Remote sensing application in agriculture water management”

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Basic computer skills with sound knowledge of MS Office

Languages Known:

Hindi, English, Malayalam

List of publications: Nil

P. S. Kiran

UNDERTAKING OF COPYRIGHT

I, **P. S. Kiran** Admission No. **2019BS37M**, hereby undertake that I give the full copyrights of my thesis entitled “**Characterization of wheat germplasm for photosynthetic pigments in response to fertilizer application grown under late sown condition**” to the **CCS Haryana Agricultural University, Hisar**.

I also undertake that the 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 Haryana Agricultural University, Hisar**.

SIGNATURE OF THE STUDENT