

ANTIOXIDATIVE DEFENSE SYSTEM AND GRAIN QUALITY EVALUATION OF HEAT TOLERANT WHEAT GENOTYPES

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
BIOCHEMISTRY
(Minor Subject: Biotechnology)**

By

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CERTIFICATE I

This is to certify that the thesis entitled “**ANTIOXIDATIVE DEFENSE SYSTEM AND GRAIN QUALITY EVALUATION OF HEAT TOLERANT WHEAT GENOTYPES**” submitted for the degree of **M.Sc.**, in the subject of **Biochemistry** (Minor subject: **Biotechnology**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ms. Amandeep Kaur (L-2011/12-BS-220-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE II

This is to certify that the thesis entitled, “**ANTIOXIDATIVE DEFENSE SYSTEM AND GRAIN QUALITY EVALUATION OF HEAT TOLERANT WHEAT GENOTYPES**” submitted by **Ms. Amandeep Kaur (L-2011/12-BS-220-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Biochemistry** (Minor subject: **Biotechnology**) has been approved by the Student’s Advisory Committee along with Head of the Department after an oral examination on the same, in collaboration with an External Examiner.

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What in me is dark?

Illumine, what is low,

Raise and support.

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ABSTRACT

The fifty genotypes of wheat in two trials Multi Location Heat Tolerance (MLHT) I and Multi Location Heat Tolerance (MLHT) II under timely and late sown conditions were sown in experimental fields of Plant Breeding and Genetics during the crop season 2011-12 to study the impact of heat stress on physiological parameters. The chlorophyll content, canopy temperature depression, days to heading, peduncle length, plant height, grain number per spike, grain weight per spike, spike number per spike, total biomass and grain yield were affected negatively under late sown conditions in all genotypes except genotypes such as GW 433, HD 3090, MP 3353, WH 1124 and RW 3705 from MLHT I and HD 3040, HI 8703, MP 3304, DBW 14, DL788-2, HUW 234 and NW 2036 from MLHT II. Genotypes GW 433, HD 3090, MP 3353 and WH 1124 from MLHT I and HD 3040, HI 8703 and MP 3304 from MLHT II were found to be less susceptible to heat stress as reflected by lower values of heat susceptibility index. Genotypes HI 1571, PBW 670, RAJ 4250 and WH 1123 from MLHT I and HI 8703, PBW 639 and WHD 946 from MLHT II were found to be susceptible to high temperature due to higher values of heat susceptibility index. Total 25 genotypes (tolerant, susceptible and checks) from both trials MLHT I and MLHT II were selected for the study of antioxidative defense system and grain quality evaluation. Genotype WH 1124 from MLHT I and genotypes HD 3040 and HI 8703 from MLHT II showed increased activity of antioxidant enzymes such as superoxide dismutase, peroxidase, ascorbate peroxidase and catalase indicated better antioxidant defense system against heat stress and hence found to be the best among the selected tolerant genotypes. GW 433, HD 3090, HD 3040 and HI 8703 from both the trials MLHT I and MLHT II showed higher grain appearance score, test weight, grain hardness, protein content, SDS-sedimentation value, grain plumpness, total sugars, dry gluten content, gluten index and better starch pasting characteristics under late sown conditions, hence can produce better quality grains. Genotypes WH 1124, HD 3090, GW 433 and HD 3040, HI 8703 from the trials MLHT I and MLHT II exhibited better antioxidative defense system and superior quality characteristics with higher yield under heat stress.

Keywords: Antioxidant enzymes, heat stress, grain quality characteristics, wheat.

Signature of Major Advisor

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ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਦੇ ਪਲਾਂਟ ਬ੍ਰੀਡਿੰਗ ਅਤੇ ਜੈਨੇਟਿਕਸ ਵਿਭਾਗ ਦੇ ਤਜਰਬਾ ਖੇਤਰ ਵਿੱਚ ਸੰਨ 2011-12 ਦੇ ਫਸਲੀ ਚੱਕਰ ਦੌਰਾਨ ਕਾਰਜਪ੍ਰਣਾਲੀ ਦੇ ਗੁਣਾਂ ਉਪਰ ਗਰਮੀ ਦਾ ਪ੍ਰਭਾਵ ਵੇਖਣ ਲਈ ਕਣਕ ਦੀਆਂ 50 ਪ੍ਰਜਾਤੀਆਂ ਨੂੰ ਸਮੇਂ ਸਿਰ ਅਤੇ ਪਿਛੇਤੀ ਬਿਜਾਈ ਵਾਲੇ ਹਲਾਤਾਂ ਅਧੀਨ ਦੋ ਤਜਰਬਿਆਂ ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਅਧੀਨ ਉਗਾਇਆ ਗਿਆ। ਪਿਛੇਤੀ ਬਿਜਾਈ ਵਾਲੇ ਹਲਾਤਾਂ ਅਧੀਨ ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਵਿੱਚ ਜੀ.ਡਬਲਯੂ. 433, ਐਚ.ਡੀ. 3090, ਐਮ.ਪੀ.3353, ਡਬਲਯੂ. ਐਚ. 1124 ਅਤੇ ਆਰ.ਡਬਲਯੂ. 3705 ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਵਿੱਚ ਐਚ.ਡੀ. 3040, ਐਚ.ਆਈ. 8703, ਐਮ.ਪੀ. 3304, ਡੀ.ਬੀ.ਡਬਲਯੂ. 14, ਡੀ.ਐਲ. 788-2, ਐਚ.ਯੂ.ਡਬਲਯੂ. 234 ਅਤੇ ਐਨ.ਡਬਲਯੂ. 2036 ਜੀਨੋਟਾਈਪਾਂ ਤੋਂ ਇਲਾਵਾ ਬਾਕੀ ਸਾਰੇ ਜੀਨੋਟਾਈਪਾਂ ਵਿੱਚ ਕਲੋਰੋਫਿਲ ਦੀ ਮਿਕਦਾਰ, ਕੈਨੋਪੀ ਤਾਪਮਾਨ ਵਿੱਚ ਆਈ ਗਿਰਾਵਟ, ਸਿੱਟੇ ਨਿਕਲਣਾ, ਪੱਤੇ ਦੀ ਡੰਡੀ ਦੀ ਲੰਬਾਈ, ਪੌਦੇ ਦੀ ਉਚਾਈ, ਪ੍ਰਤੀ ਬੱਲੀ ਦਾਣਿਆਂ ਦੀ ਸੰਖਿਆ, ਪ੍ਰਤੀ ਬੱਲੀ ਦਾਣਿਆਂ ਦਾ ਭਾਰ, ਪ੍ਰਤੀ ਬੱਲੀ ਸਿੱਟਿਆਂ ਦੀ ਗਿਣਤੀ, ਕੁੱਲ ਸੁੱਕਾ ਮਾਦਾ ਅਤੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ ਉਪਰ ਰਿਣਾਤਮਕ ਪ੍ਰਭਾਵ ਪਿਆ। ਗਰਮੀ ਪ੍ਰਤੀ ਸਹਿਣਸ਼ੀਲ ਅੰਕ ਦੇ ਘੱਟ ਹੋਣ ਪਤਾ ਚੱਲਿਆ ਕਿ ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਵਿੱਚ ਡੀ.ਡਬਲਯੂ. 433, ਐਚ.ਡੀ. 3090, ਐਮ.ਪੀ. 3353 ਅਤੇ ਡਬਲਯੂ.ਐਚ. 1124 ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਵਿੱਚ ਐਚ.ਡੀ. 3040, ਐਚ.ਆਈ. 8703 ਅਤੇ ਐਮ.ਪੀ. 3304 ਜੀਨੋਟਾਈਪ ਗਰਮੀ ਪ੍ਰਤੀ ਘੱਟ ਸੰਵੇਦਨਸ਼ੀਲ ਸਨ। ਤਾਪਮਾਨ ਪ੍ਰਤੀਸਹਿਣਸ਼ੀਲ ਅੰਕ ਤੋਂ ਚੱਲਿਆ ਕਿ ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਵਿੱਚ ਐਚ.ਆਈ. 1571, ਪੀ.ਬੀ.ਡਬਲਯੂ. 670, ਆਰ.ਏ.ਜੇ. 4250 ਅਤੇ ਡਬਲਯੂ.ਐਚ. 1123 ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਵਿੱਚ ਐਚ.ਆਈ. 8703, ਪੀ.ਬੀ.ਡਬਲਯੂ. 639 ਅਤੇ ਡਬਲਯੂ.ਐਚ.ਡੀ. 946 ਜੀਨੋਟਾਈਪ ਤਾਪਮਾਨ ਪ੍ਰਤੀ ਸੰਵੇਦਨਸ਼ੀਲ ਸਨ। ਦਾਣਿਆਂ ਦੀ ਗੁਣਵਤਾ ਦੇ ਮੁਲਾਂਕਣ ਅਤੇ ਐਂਟੀਆਕਸੀਡੈਂਟ ਸੁਰੱਖਿਆ ਪ੍ਰਣਾਲੀ ਦੇ ਅਧਿਐਨ ਲਈ ਕੁੱਲ 25 ਪ੍ਰਜਾਤੀਆਂ (ਸਹਿਣਸ਼ੀਲ, ਸੰਵੇਦਨਸ਼ੀਲ ਅਤੇ ਚੈੱਕ) ਨੂੰ ਚੁਣਿਆ ਗਿਆ। ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਦੀ ਡਬਲਯੂ.ਐਚ. 1124 ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਦੀ ਐਚ.ਡੀ. 3040 ਅਤੇ ਐਚ.ਆਈ. 8703 ਪ੍ਰਜਾਤੀ ਵਿੱਚ ਐਂਟੀਆਕਸੀਡੈਂਟ ਇੰਜ਼ਾਈਮ ਜਿਵੇਂ ਕਿ ਸੁਪਰਆਕਸਾਈਡ ਡਿਸਮੁਟੇਜ਼, ਪਰਆਕਸੀਡੇਜ਼, ਐਸਕਾਰਬੇਟ ਪਰਆਕਸਾਈਡ ਅਤੇ ਕੈਟਾਲੇਜ਼ ਦੀਆਂ ਗਤੀਵਿਧੀਆਂ ਵਿੱਚ ਵਾਧਾ ਹੋਇਆ ਜਿਸ ਤੋਂ ਗਰਮ ਹਲਾਤਾਂ ਪ੍ਰਤੀ ਇਹਨਾਂ ਦੀ ਐਂਟੀਆਕਸੀਡੈਂਟ ਸੁਰੱਖਿਆ ਪ੍ਰਣਾਲੀ ਦਾ ਪਤਾ ਚੱਲਿਆ ਅਤੇ ਇਹ ਪਾਇਆ ਗਿਆ ਕਿ ਇਹ ਪ੍ਰਜਾਤੀਆਂ ਚੁਣੀਆਂ ਗਈਆਂ ਸਹਿਣਸ਼ੀਲ ਪ੍ਰਜਾਤੀਆਂ ਵਿੱਚੋਂ ਸਭ ਤੋਂ ਵਧੀਆ ਸਨ। ਪਿਛੇਤੀ ਬਿਜਾਈ ਵਾਲੇ ਹਲਾਤਾਂ ਅਧੀਨ ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਤਜਰਬਿਆਂ ਦੇ ਜੀ.ਡਬਲਯੂ. 433, ਐਚ.ਡੀ. 3090, ਐਚ.ਡੀ. 3040 ਅਤੇ ਐਚ.ਆਈ. 8703 ਜੀਨੋਟਾਈਪਾਂ ਦੇ ਦਾਣਿਆਂ ਦੇ ਆਕਾਰ ਦਾ ਅੰਕ, ਟੈਸਟ ਭਾਰ, ਦਾਣਿਆਂ ਦੀ ਠੋਸਤਾ, ਪ੍ਰੋਟੀਨ ਦੀ ਮਿਕਦਾਰ, ਐਸ.ਡੀ.ਐਸ.-ਸੈਡੀਮੈਂਟੇਸ਼ਨ ਅੰਕ, ਦਾਣਿਆਂ ਦੀ ਮੋਟਾਈ, ਕੁੱਲ ਸ਼ੂਗਰ, ਸੁੱਕੇ ਗਲੂਟੇਨ ਦੀ ਮਿਕਦਾਰ, ਗਲੂਟੇਨ ਅੰਕ ਅਤੇ ਵਧੀਆ ਸਟਾਰਚ ਪੇਸਟਿੰਗ ਗੁਣ ਵਧੀਆ ਪਾਏ ਗਏ, ਇਸ ਤਰ੍ਹਾਂ ਇਹਨਾਂ ਦੇ ਦਾਣਿਆਂ ਦੀ ਗੁਣਵਤਾ ਵਧੇਰੇ ਸੀ। ਐਮ.ਐਲ.ਐਚ.ਟੀ. I ਅਤੇ ਐਮ.ਐਲ.ਐਚ.ਟੀ. II ਦੇ ਡਬਲਯੂ.ਐਚ. 1124, ਐਚ.ਡੀ. 3090, ਜੀ.ਡਬਲਯੂ. 433 ਅਤੇ ਐਚ.ਡੀ. 3040, ਐਚ.ਆਈ. 8703 ਜੀਨੋਟਾਈਪਾਂ ਦੀ ਐਂਟੀਆਕਸੀਡੈਂਟ ਸੁਰੱਖਿਆ ਪ੍ਰਣਾਲੀ, ਗੁਣਵਤਾ ਦੇ ਗੁਣ ਅਤੇ ਝਾੜ ਵਧੀਆ ਸਨ।

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CONTENTS

CHAPTER	TOPIC	PAGE NO.
I.	INTRODUCTION	1-3
II.	REVIEW OF LITERATURE	4-13
III.	MATERIAL AND METHODS	14-22
IV.	RESULTS AND DISCUSSION	23-122
V.	SUMMARY	123-125
	REFERENCES	126-136
	APPENDIX	I
	VITA	

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the major staple food crop grown worldwide on more than 17% of the cultivatable land and produced in a wide range of climatic environment systems. It is the most important staple food of about two billion people (36% of the world population). Wheat cultivation in India started 5000 years ago (Feldman 2001). It is the most widely grown cereal in temperate environments and is also cultivated in many tropical regions. It is often grown as the winter season crop in rotation with a number of other crops. It is the leading cereal grain produced, consumed and traded in the world. It is also an important part of the daily diet of millions of people. It provides more than 50 percent of the total calories and 60 percent of the total proteins consumed by the world population as a whole. During the past four decades, wheat has made a significant contribution to the increase in global food production as total production rose steadily through the use of higher yielding, water and fertilizer-responsive, and disease-resistant varieties supported by a strengthened input system, tailored management practices, and improved marketing (Dixon *et al* 2009).

April 2014, the United States Department of Agriculture (USDA) estimates that the World Wheat Production 2013/14 will be 712.52 million metric tons, around 0.19 million tons less than the previous year projection. The global average wheat yield must be increase during the coming 25 years from 2.6 to 3.5 tones ha⁻¹. India is the second largest producer of the wheat after china with 25 million ha area and 70 million tones production on an average. The targeted Indian wheat production for the year 2030 is approximately 95 million tons. In Punjab it occupies the largest area of 3528 hectares among the cereals, with production of 17982 metric tons.

To feed the ever-increasing population in the country, the need for more wheat will stay. Among the numerous advantages of cultivating wheat in cropping system are that it is relatively high yielding and easy to transport and store. There are also disadvantages linked to growing wheat in tropical areas (Reynolds *et al* 2000). Crop shows its maximum yield potential in stress free environment while environmental stress causes reduction in this potential.

Abiotic factors are the major threat to wheat productivity and causing up to 71% reduction in yield. Temperatures above the optimum for growth can be deleterious, causing injury or irreversible damage, which is generally called 'heat stress'. Heat stress is a function of the magnitude and rate of temperature increase, as well as the duration of exposure to the raised temperature (Wahid *et al* 2007). Wheat (*Triticum aestivum* L.) is very sensitive to high temperature (Slafer and Satorre 1999) and trends in increasing growing season temperatures

have already been reported for the major wheat-producing regions (Alexander *et al* 2006, Hennessy *et al* 2008). Wheat experiences heat stress to varying degrees at different phenological stages, but heat stress during the reproductive phase is more harmful than during the vegetative phase due to the direct effect on grain number and dry weight (Wollenweber *et al* 2003). High temperature limits the productivity of crops in many regions of the world (Al-Khatib and Paulsen 1999).

End-of-season or 'terminal' heat stress is also likely to increase for wheat in the near future (Mitra and Bhatia 2008, Semenov 2009). Temperature is the determinant factor for the geographical distribution of plant species, with heat stress being the main factor limiting the growth of cool season plant species (Jiang and Huang 2001). The rate of temperature change, intensity and duration are the main factors determining the severity of temperature stress (Sung *et al* 2003). According to an estimate, there are around 9 million hectares of wheat in tropical or subtropical areas that experience yield losses due to high temperature stress. However, in Indian alone around 13.5 million hectares of area is heat stressed (Joshi *et al* 2007).

Besides the physiological changes, heat stress induces water deficit and oxidative stress, triggering a variety of plant responses, such as altered gene expression and cellular metabolism and resulting in changes in growth rate and final crop yield. The heat-induced oxidative stress is always linked with the expression of antioxidant enzymes (Kochhar and Kochhar 2005). Antioxidant enzymes production is triggered by the increased level of reactive oxygen species (ROS), which are produced when the cellular homeostasis is disrupted. Reactive oxygen species are harmful to living cells and disrupt the normal metabolism by damaging lipids, nucleic acids and proteins. Thus for normal metabolism to take place in plants, efficient removal of ROS is of paramount importance. ROS-scavenging system/antioxidant defense system include enzymes such as superoxide dismutase (SOD), peroxidase (POX), glutathione reductase (GR), ascorbate peroxidase (APX) and catalase (CAT) and nonenzymatic substances such as ascorbic acid, glutathione and α -tocopherol, which play a role in the detoxification of ROS in Aerobic cells (Badawi *et al* 2007). Plants have endogenous protective mechanisms including glutathione, ascorbate and carotenoids and enzymes such as superoxide dismutase, glutathione reductase, peroxidase and catalase which scavenge and remove toxic products (Halliwell 1982).

The equilibrium between the production and the scavenging of ROS may be perturbed by various biotic and abiotic stress factors such as drought, UV radiation, salinity, heavy metals, temperature extremes, nutrient deficiency, air pollution, herbicides and pathogen attacks. These disturbances in equilibrium lead to a sudden increase in the intracellular levels of ROS, which can cause significant damage to cell structures (Gill and

Tuteja 2010). Dynamic changes in the antioxidant enzyme activities in wheat genotype have been attributed as an important anti-stress mechanism to cope with oxidative stress induced due to high temperature. Therefore antioxidant defense mechanism plays an important role in the heat stress tolerance of wheat genotypes (Almeselmani *et al* 2009).

Many quality characteristics are important for the utilization of wheat, particularly flour protein concentration, milling yield, rheological and baking properties. These characteristics usually are influenced by cultivar and interaction of cultivar and environment. Although quality traits are mainly due to potential of the cultivar, but the role and effect of environment on wheat quality can be large (Souza *et al* 2004). Cultivars differ significantly in their response of end-use quality, to the detrimental effects of heat stress. Extreme temperature stress is especially important to wheat quality during grain development as it affects pattern of accumulation of gluten protein, starch, enzymes and other biomolecules that collectively give wheat its unique ability to be transformed into tasty food products (Jiang *et al* 2009). High temperature can significantly elevate protein content while lowering the functionality of protein, ultimately changing the rheological properties of flour (Motzo *et al* 2007).

As global warming increases in the future, with projected increase in temperature, high temperature is anticipated to become increasingly limiting factor for growth of many plant species, especially the winter season crop such as wheat (Gulen and Eris 2004). Growing food demand for the increasing population and global warming are further pushing the wheat crop to heat stress environments (Vishwanathan and Khanna-Chopra 2001), the development of heat tolerant varieties is a global concern. Increasing crop tolerance to heat stress would be the most economical approach to improve crop productivity and satisfy the food requirement of growing population. Review of literature revealed that research work has already been initiated in this direction but only few reports are available separately for defense mechanism study of heat tolerance and for quality and functionality of heat tolerant genotypes. Since quality of wheat is much important, so need to identify new genotypes which can tolerate the elevated temperatures and also produce better quality grains. Keeping in view the rising temperature and the increasing demand for wheat among domestic consumers and also the industries, the present study was planned with the following objectives:

- To study the antioxidant defense system of selected heat tolerant and susceptible genotypes on the basis of physiological observations.
- To evaluate grain quality of selected heat tolerant and susceptible genotypes on the basis of physiological observations.

CHAPTER II

REVIEW OF LITERATURE

Exposure to high temperature or heat is one of the major stresses for wheat, restricting its growth, productivity and reducing the quality of harvested products. Wheat in India is invariably exposed to extreme temperatures during some stages of development. All stages of wheat development are sensitive to temperature. The daily maximum temperatures of more than 32°C for a few days during the ripening period, commonly encountered in the Indian subcontinent interferes with grain filling and maturation process.

Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development. In general, a transient elevation in temperature, usually 10–15 °C above ambient, is considered heat shock or heat stress. However, heat stress is a complex function of intensity (temperature in degrees), duration and rate of increase in temperature. The extent to which it occurs in specific climatic zones depends on the probability and period of high temperatures occurring during the day and/or the night.

Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperatures. However, while some researchers believe that night temperatures are major limiting factors others have argued that day and night temperatures do not affect the plant independently and that the diurnal mean temperature is a better predictor of plant response to high temperature with day temperature having a secondary role (Peet and Willits 1998).

2.1 Physiological characteristics

Various physiological injuries have been observed under elevated temperatures, such as scorching of leaves and stems, leaf abscission and senescence, shoot and root growth inhibition or fruit damage, which consequently lead to decreased plant productivity (Vollenweider and Günthardt-Goerg 2005). In many cases, plant architecture changes and hypocotyls and petioles elongate resembling the morphological responses of shade avoidance (Tian *et al* 2009). However, high temperatures reduce plant growth by affecting the shoot net assimilation rates and thus the total dry weight of the plant (Wahid *et al* 2007).

The detrimental effects of heat on chlorophyll and the photosynthetic apparatus are also associated with the production of injurious reactive oxygen species (Camejo *et al* 2006, Guo *et al* 2007). By increasing chlorophyllase activity and decreasing the amount of photosynthetic pigments, heat stress ultimately reduces the plant photosynthetic and respiratory activity (Sharkey and Zhang 2010).

Crop plants are immobile and they must adapt to prevalent soil and weather conditions. Except for transpirational cooling, plants are unable to adjust their tissue

temperatures to any significant extent. The traits affecting radiation use efficiency (such as early ground cover, stay-green and photosynthetic rate) could be expected to be important under heat stress. Different physiological mechanisms may contribute to heat tolerance in the field for example, higher photosynthetic rate, chlorophyll content, membrane thermostability and heat avoidance as indicated by canopy temperature depression (CTD). Since CTD is directly or indirectly affected by a number of physiological processes, it is a good indicator of a genotype's fitness in a given environment (Reynolds *et al* 1998).

Leaf chlorophyll content was estimated by using a portable chlorophyll meter (CM-1000, Spectrum Tech, Plainfield, Ill. USA). CM-1000 readings were made in situ on the plants designated for harvesting, midway along the youngest fully expanded leaf. The Minolta SPAD 502 chlorophyll meter has become recognized as a reliable substitute for total chlorophyll (Bauerle *et al* 2004, Van den Berg and Perkins 2004, Netto *et al* 2005). The CM1000 chlorophyll meter was utilized and investigated as a potential substitute for the SPAD meter in applications with small leaves and where measurements were difficult to make.

Height is a crucial component of a plant species' ecological strategy. It is central to a species' carbon gain strategy, because height is a major determinant of a plant's ability to compete for light and because of correlations between plant height and traits such as leaf mass fraction, leaf area ratio, leaf nitrogen per area, leaf mass per area and canopy area (Falster and Westoby 2003). Plant height is also an important part of a coordinated suite of life-history traits including seed mass, time to reproduction, longevity and the number of seeds a plant can produce per year (Moles and Leishman 2008). In temperate and tropical low-lands, heat susceptibility is a cause of yield loss in common bean, *Phaseolus vulgaris* (Rainey and Griffiths 2005) and groundnut, *Arachis hypogaea* (Vara Prasad *et al* 1999).

The number of grains per spike usually remains constant among heat stressed and control genotypes, which is a well-known effect (Dias and Lidon 2009). As seen by scanning electron microscopy, the increasing temperatures (from 25/14 to 31/20°C), during grain growth, decreases grain size and promotes grain shrinking, thus implicating a reduction of individual grain weight (Dias and Lidon 2009). In the heat stressed genotypes, tolerance and sensitivity is expressed by different grain weight and therefore yield, mostly due to a significantly different potential grain weight and grain filling rate (Dias and Lidon 2009).

Wheat varieties with satisfactory genetic traits are essential for the production of high quality wheat. Certain quality parameters vary over a very wide range in individual breeding lines. This broad genetic variability is demonstrated by the fact that the protein content ranges from 10–17%, the gluten content from 20–45%, the grain hardness from 10–85, the falling number from 60–450, and the farinograph index from C2 to A1. These differences in quality

also depend on the soil, nutrient supplies, standard of plant protection, and other agronomic factors. The weather conditions during the growing season, especially the rainfall quantity and temperature, have a substantial influence on the plant metabolic processes, and thus on wheat quality. Stress during the grain-filling stage may have an even greater effect on wheat, as it may cause reduced grain-filling (Wardlaw and Moncur 1995), accelerated cell death and an earlier attainment of the harvest maturity (Altenbach *et al* 2003), which may result in substantial changes in the protein composition of the grains and in the size distribution of starch granules. The yield losses are caused by a reduction in the starch content, since over 65% of cereal kernel is composed of starch (Barnabas *et al* 2008). While important findings on the impact of heat on crop yield have been made based on experiments in controlled environments, little is known about the effects under field conditions at larger scales. The study of Deryng *et al* (2014) global crop yield response to extreme heat stress under multiple climate change futures analysing the impact of heat stress on maize, spring wheat and soya bean under climate change, represents an important contribution to this emerging research field. Starch accumulation is correlated with the sucrose content of the kernels and with the activity of sucrose synthase and other enzymes with an important role in starch synthesis (Yan *et al* 2008). This suggests that low sucrose content and a decline in the enzymatic activity involved in starch synthesis are responsible for the reduction of starch accumulation. According to Labuschagne *et al* (2009), the lower ratio of starch in the endosperm in response to high temperature can be attributed to the heat inactivation of starch synthase, the key enzyme in the starch biosynthesis reaction pathway (Denyer *et al* 1994). The functional properties of starch, especially the water absorption ability of starch or flour and the flexibility of the dough are dependent on the amylose-to-amylopectin ratio and the size distribution of the starch granules (Labuschagne *et al* 2009). Considerable changes in the size and shape of starch granules are also observed when starch is incorporated into the endosperm during ripening (Stoddard 1999, Hurkman *et al* 2003). It was demonstrated that even a low light intensity may have an effect on various types of starch granules, resulting in a sudden decline in the grain yield and in the starch content of the kernels. B-type starch granules ($\leq 9.9 \mu\text{m}$) proved to be much more sensitive to shading and high temperature during the grain-filling period than A-type granules ($> 9.9 \mu\text{m}$) (Blumenthal *et al* 1995, Li *et al* 2008, 2010). Various authors (Chinnusamy and Khanna-Chopra 2003, Hurkman *et al* 2003, Zhao *et al* 2008) reported that a high temperature after flowering reduced the starch content and had a significant influence on the starch granule size distribution in the wheat kernels. The number of B-type granules decreases in response to high temperature while that of A-type granules rose. In some of the varieties tested, drought after flowering also reduced the % volume and surface area of B-type granules ($< 10 \mu\text{m}$) (Zhang *et al* 2010). Flour properties are closely

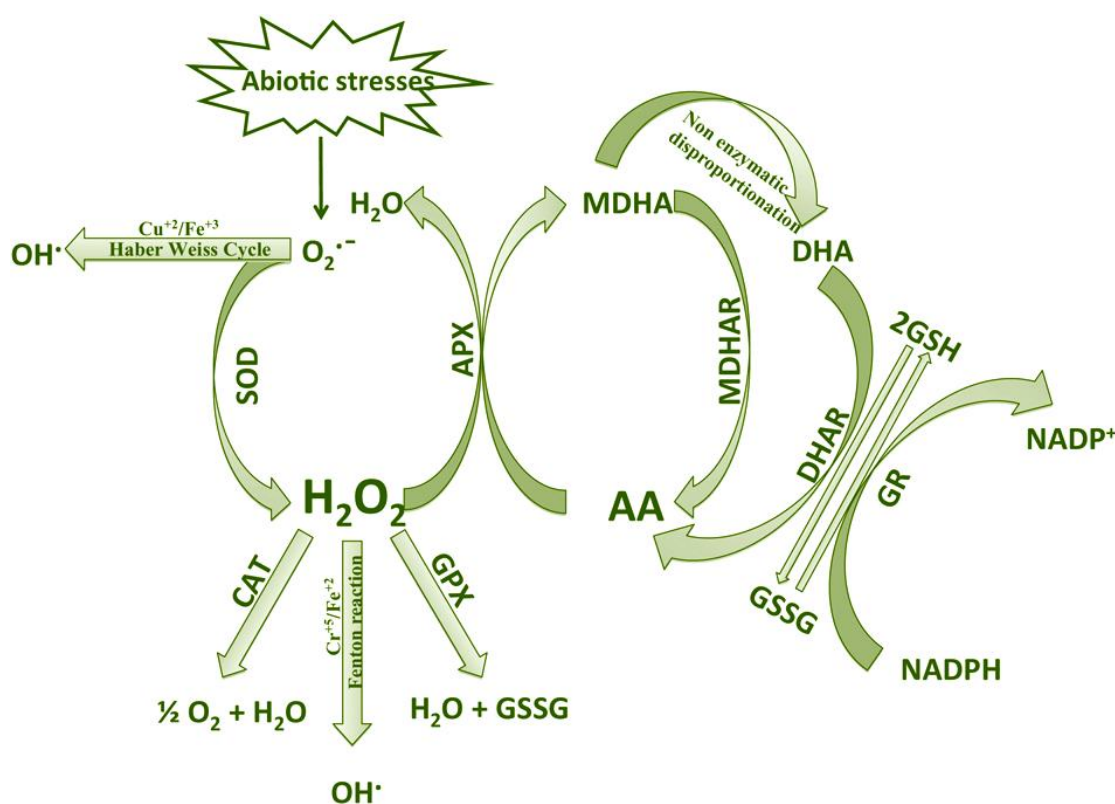
associated with the starch granule size distribution (Soh *et al* 2006), large (A-type) granules leading to lower maximum viscosity in comparison with small (B-type) granules. These differences mean that the two types of starch granules are differently utilised in processed foods and non-food products.

Protein accumulation also changes in response to stress. Instead of the proteins that play an active role in the biosynthesis and metabolism, storage proteins and those involved in protecting the plants against biotic and abiotic stresses are accumulated preferentially. Specific protein responses depend on whether or not high temperature occurs during the early or middle phases of grain-filling (Hurkman *et al* 2009). The protein content in flour increases significantly with bread wheat as the result of the heat stress (Balla and Veisz 2007, Labuschagne *et al* 2009), a phenomenon also noted by other authors (Corbellini *et al* 1997, Daniel and Triboi 2000, Hrušková and Švec 2009). The application of N after flowering may indirectly increase the protein content of the kernels without reducing the yield, while the increased grain protein content caused by heat and drought stress after flowering may be associated with yield losses due to a reduction in the starch production (Cassman *et al* 1992, Fowler 2003). The protein composition, which is the most decisive factor in breadmaking quality, is greatly influenced by various types of stresses. The gluten proteins, glutenin and gliadin are responsible for the flexibility and extensibility of the dough. Although albumins-globulins have only a slight influence on the dough quality, they are important from the nutritional point of view, due to their high contents of essential amino acids. Gupta *et al* (1992) and Triboi *et al* (2003) reported an increase in the gliadin proportion and a reduction in the glutenin proportion as the protein content of the flour increased. The ratio of albumins-globulins did not increase proportionately with the protein content in response to a rise in temperature. It was demonstrated by Zhao *et al* (2009) that protein components are very sensitive to drought stress during the later phases of grain-filling. The deterioration in the dough quality could be attributed to the decline in the glutenin-to-gliadin ratio and in the percentage of very large glutenin polymers in response to stress.

High temperature (Blumenthal *et al* 1995, Bencze *et al* 2004, Balla and Veisz 2007). In Hungary, high temperature and drought occur most frequently after heading, during the grain-filling period, causing stress that influences the quality of the wheat kernels. One of the main aims of the present work was thus to analyse the changes in the nutrient content, quality and quantity of the yield of a wide range of wheat varieties under various environmental conditions, including high temperature and drought stress during ripening. The measurements involved the protein content of the kernels, proportion of protein components, and the size of starch granules produced from stressed plants.

2.2 Biochemical role of antioxidative defense mechanism

Reactive oxygen species (ROS) are produced by all aerobic organisms as inevitable by-products of several metabolic pathways, including electron flows in mitochondria and chloroplasts, lipid catabolism and photorespiration in glyoxysomes and peroxisomes, as well as enzymatic oxygenase reactions having a different cellular localization. In order to avoid ROS toxicity, aerobic cells are provided with a flexible set of enzymes and metabolites involved in ROS catabolism, which often acts at the site of ROS production. Despite much metabolic energy being spent on ROS removal by plant cells, ROS are also actively produced by cell metabolism under optimal growth conditions (Heath 2000). Fortunately, cells make a variety of antioxidant enzymes to fight the dangerous side-effects of life with oxygen. Stress-induced reactive oxygen species (ROS) accumulation is counteracted by enzymatic antioxidant systems that include a variety of enzymatic scavengers, such as superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidase (GPX) and catalase (CAT), and non-enzymatic low molecular metabolites, such as ascorbic acid (ASH), glutathione (GSH), α -tocopherol, carotenoids and flavonoids (Mittler *et al* 2004 and Gratao *et al* 2005). Badawi *et al* (2007) investigated induction of antioxidant enzymes such as superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR) and catalase (CAT) along with stomatal conductance in wheat shoot under high temperature stresses.



High levels of antioxidant enzymes, both constitutively or induced, could explain the inheritant ability to withstand or suffer from high temperature environment. Almeselmani

et al (2009) reported that the superoxide dismutase, ascorbate peroxidase, catalase, glutathione reductase and peroxidase activities increased significantly at all stages of growth in C 306 in response to heat stress treatment, while PBW 343 showed a significant reduction in catalase, glutathione reductase and peroxidase activities in the high temperature treatment. The hydrogen peroxide content increased as the plants advanced in age and higher hydrogen peroxide content was recorded in PBW 343 than in C 306 at different stages of growth in the heat stress treatment. From the results it is apparent that the antioxidant defense mechanism plays an important role in the heat stress tolerance of wheat genotypes. The activity of enzymes associated with the antioxidant defense system, especially ascorbate peroxidase has been shown to increase rapidly under heat stress in mustard (Dat *et al* 1998).

Two important players are superoxide dismutase, which converts superoxide radicals into hydrogen peroxide and catalase, which converts hydrogen peroxide into water and oxygen (Apel and Hirt 2004). Superoxide dismutases (SOD; EC 1.15.1.1) are enzymes that catalyze the dismutation of superoxide into oxygen and hydrogen peroxide. Thus, they are an important antioxidant defense in nearly all cells exposed to oxygen. In higher plants, SOD isozymes have been localized in different cell compartments. For example Mn-SOD is present in mitochondria and peroxisomes. Fe-SOD has been found mainly in chloroplasts but also has been detected in peroxisomes and CuZn-SOD has been localized in cytosol, chloroplasts, peroxisomes, and apoplast (Corpas *et al* 2006).

Catalase (EC 1.11.1.6), is nearly ubiquitous among organisms that can grow in the presence of oxygen. The major function of catalase within cells is to prevent the accumulation of toxic levels of hydrogen peroxide formed as a by-product of metabolic processes - primarily that of the electron transport pathway (Apel and Hirt 2004). Catalase, which normally accompanies SOD, is found in almost all cells, but may be found in its highest content in hydroponically grown concentrated wheat sprouts. Catalase was one of the first enzymes to be purified to homogeneity and has been the subject of intense study. This enzyme is among the most efficient known with rates approaching 200,000 catalytic events/second/subunit (near the diffusion-controlled limit) (Shahbazi *et al* 2009).

Potential applications of catalases in medicine and industry have led to numerous attempts to engineering this protein (Shaked and Wolfe 1988). Catalase has also gained attention in recent years because of its link to cancer, ageing in humans and animals. The application of catalases for the elimination of H_2O_2 in textile bleaching effluents would not only allow the recycling of enormous amount of water used for dyeing but would also have advantage over the use of unfavorable high quantities of salt concentrations such as sodium bisulfite and act as a more environmentally friendly alternative to existing chemical treatments. Most of the commercial catalases available in the market are optimally active at

20-50°C and at neutral pH this necessitates the requirement of new thermoalkalstable catalases which can act at temperatures above 50°C and pH values above 9.0. Catalases are not restricted to one protein type structurally, functionally or by sequence.

Glutathione reductase (GR) is found in both prokaryotes and eukaryotes (Romero-Pueetas *et al* 2006). It is involved in the ASA-GSH cycle and plays important role in defense against ROS by sustaining the reduced status of GSH. It is localized in chloroplasts, but small amount of this enzyme is also found in mitochondria and cytosol (Edward *et al* 1990). Glutathione reductase plays an important role in the protection of chloroplasts against oxidative damage by maintaining a high GSH/GSSG ratio (Gamble and Burke 1984). It has been suggested that glutathione reductase helps in the resistance of plants against oxidative stress generated by high oxygen pressure.

Glutathione transferases (GSTs) (EC 2.5.1.18) are a super family of multifunctional proteins with fundamental roles in the cellular detoxification of a wide range of exogenous and endogenous compounds. Although several of them are not transferases at all, these proteins are still collectively called GSTs, probably because the first discovered ones were indeed transferases and as such they will be referred to throughout this review. In plants and animals, GSTs are the principal phase II enzymes in metabolic detoxification processes. Their main chemistry is to catalyze the conjugation of the tripeptide glutathione (GSH: g-Glu-Cys-Gly) with compounds containing an electrophilic centre to form more soluble nontoxic peptide derivatives, ready to be excreted or compartmentalized by phase III enzymes (Coleman *et al* 1997). In addition, GSTs can serve as peroxidases, isomerases and thiol transferases (Bartling *et al* 1993, Fernandez-Can˜on and Pen˜alva 1998, Board *et al* 2000) or have non-catalytic functions among which binding of non-substrate ligands and modulation of signaling processes (Mueller *et al* 2000, Smith *et al* 2003, Axarli *et al* 2004). The original view of GSTs as solely detoxication enzymes has thus gradually changed and their roles extended to non-stress metabolism, as leukotriene and prostaglandin biosynthesis (Kanaoka *et al* 1997, Jakobsson *et al* 1999) and the catabolism of aromatic aminoacids.

Ascorbate peroxidase (APX) (EC 1.11.1.11) are thought to play the most essential role in scavenging ROS and protecting cells in higher plants, algae, euglena and other organisms. It is constitutively expressed in roots, leaves, stems, and many other plant tissues, and its expression is significantly up regulated in response to a large number of biotic and abiotic stresses (Zimmermann *et al* 2004). APX is involved in scavenging of H₂O₂ in water-water and ASH-GSH cycles and utilizes ASH as the electron donor. The APX family consists of at least five different isoforms including thylakoid (tAPX) and glyoxisome membrane forms (gmAPX), as well as chloroplast stromal soluble form (sAPX), cytosolic form (cAPX). APX

has higher affinity for H₂O₂ (μM range) than CAT and POX (mM range) and it may have a more crucial role in the management of ROS during stress.

ROS cause lipid peroxidation and membrane damage (Monterio *et al* 2009). At cellular level, lipid peroxidation is the most significant damage caused by ROS. Malondialdehyde (MDA, the product of lipid peroxidation) level is regarded as a biochemical marker for injury mediated by ROS (Verma and Dubey 2003).

H₂O₂ is produced in plant cells during photorespiration and photosynthesis, also in lesser extent in respiration. It plays a crucial role as a signaling molecule in various physiological processes. Hydrogen peroxide interacts with thiol-containing proteins and activates different signaling pathways as well as transcription factors, which in turn regulate gene expression and cell cycle processes (Slesak *et al* 2007). It is also been shown to act as a key regulator in a broad range of physiological processes such as senescence (Peng *et al* 2005).

The equilibrium between the production and the scavenging of ROS may be perturbed by various biotic and abiotic stress factors such as drought, UV radiation, salinity, heavy metals, temperature extremes, nutrient deficiency, air pollution, herbicides and pathogen attacks. These disturbances in equilibrium lead to a sudden increase in the intracellular levels of ROS, which can cause significant damage to cell structures (Gill and Tuteja 2010).

2.3 Quality characteristics

The heat induced reduction in wheat yield and quality is attributed to negative effects of heat stress on plant physiological and metabolic processes (Bukovnik *et al* 2009). High temperatures reduce productivity not only by limiting grain set or grain filling but also affecting the grain quality. Quality of wheat is usually judged by its suitability for a particular end use and is largely a relative concept and is considered in relation to a particular crop. A wide range of environmental stresses such as high and low temperature, drought, alkalinity, salinity, UV stress and pathogen infection, are potentially harmful to the plants (Marvi *et al* 2011).

Johnson *et al* (1972) reported a significant relationship between protein content and elevated temperature during early grain filling but the author did not find the same for late grain filling. Kolderup (1975) concluded that the protein content and its composition was affected by the temperature because the ratio of alkali soluble proteins increased with increasing temperature.

Starches with varying pasting characteristics are of interest for food processing because of the potential to modify the texture and quality of the end-use products. Small

starch granules have been reported to increase the extensibility of the dough whereas large granules increase the resistance to extension (Larson and Eliasson 1997).

Moisture stress caused an increase in protein content and a reduction in thousand kernel weight. Limited water input during grain filling decreased grain quality by reducing test weight and SDS sedimentation volume and by increasing ash content (Rharrabtia *et al* 2003).

When breeding for wheat quality, the SDS-sedimentation (SDS) test is commonly used to predict gluten strength (Brites and Carrillo 2001). This is rapid gluten strength-related screening tests applied mainly to common wheat. The lactic acid retention capacity (LARC) test was designed to estimate gluten strength of soft wheat (Gaines 2000) and it was highly positively associated with gluten strength parameters of Farinograph and Mixograph (Ram *et al.*, 2005). The swelling index of glutenin (SIG) was recently developed for estimating insoluble glutenin content, and can be used for predicting gluten strength (Wang and Kovacs 2002).

Stone and Nicholas (1994) reported on two extreme genotypes from a survey of a large number of wheats that had been heat-stressed in the glasshouse: cv. Osprey showed a dramatic decrease in glutenin-to-gliadin ratio and little change for cv. Egret. Bernardin *et al* (1995) reported no significant differences in glutenin-to-gliadin ratio for five U.S. wheat as a result of many days of heat stress at 40 °C. They did, however, detect considerable increases due to heat stress in proteins associated with the heat shock response.

The proportion of glutenins and gliadins, the proportion and composition of HMW-GS and LMWGS, and the amount of soluble and insoluble glutenins, all have close relationships with dough rheological properties and bread baking quality (Veraverbeke and Delcour 2002).

Grain hardness, moisture, grain and flour protein were determined by near-infrared spectroscopy (NIRS) (Foss NIR systems and INFRATEC 1255 Food & Feed Analyzer) calibrated based on AACC methods (AACC, 2000) for particle size index (AACC Method 55-30); moisture (AACC Method 44-15A); and protein (AACC Method 46-11A). Lower hardness index (%) values correspond to harder cultivars. Grain protein and flour protein were adjusted to 12.5% and 14% moisture basis, respectively. Drought stress applied during wheat grain development considerably reduced the SDS sedimentation volume and this was found to be mainly dependent on the timing of stress imposition (Gooding *et al* 2003).

The process of starch accumulation in cereal grains is mediated by enzymes including sucrose synthase (SuSy), ADP-glucose pyrophosphorylase (AGPase), soluble starch synthase (SSS) and starch branching enzyme (SBE) (Morell *et al* 2001, Barnabás *et al* 2008). The

activities of these enzymes have been correlated with starch synthesis in wheat grains under water limited conditions.

Castro (2006) observed that heat stress imposed early during grain filling had the greater effect. He also found that under field condition moderate to high heat stress in mid-grain fill increased test weight and thousand kernel weight while higher heat stress under controlled environment caused a decrease in thousand kernel weight, without any relation to duration or timing of heat stress. He recorded a curvilinear relationship for heat stress to grain weight. But Tahir et al (2006) observed genotypic differences in response to high soil temperature and high air/soil temperature.

CHAPTER III

MATERIAL AND METHODS

Two trials MLHT I and MLHT II of 25 wheat genotypes each were grown in experimental fields of Plant Breeding and Genetics under two dates of sowing i.e. timely sown (25 Nov.) and late sown (23 Dec) during the year 2011-12.

MLHT I:- HI8703, DBW90, DPW621-50, GW431, GW432, GW433, HD2864, HD3040, HD3091, HI1571, HD3095, HD3096, HI1563, HUW234, MP3353, NIAW1689, PBW670, RAJ4250, RAJ3765, RSP561, RW3705, UAS320, HD3932, WH1123, WH1124

MLHT II:- AKAW4210-6, DBW14, DL788-2, HD2864, HD2932, HD3040, HI1563, HD1571, HI8703, HI8704, HUW234, LOK62, MP3304, MP4010, NIAW34, NW2036, PBW373, PBW590, PBW639, PDW322, RAJ4083, UAS320, UAS428, WH1021, WHD946 .

3.1 OBSERVATIONS RECORDED IN FIELD:

Data on chlorophyll content, canopy temperature depression, days to heading, plant height, peduncle length, grain weight per spike, number of spikelets/spike, number of grains/spike, grain yield, total biomass and heat susceptibility index was recorded as follow:

1. **Chlorophyll content: SPAD Readings:** The mean of three readings from a portable Atleaf chlorophyll meter SPAD-502 was obtained for each leaf disc from individual leaves (5 leaves per plant) and pooled to obtain one SPAD measurement per disc.
2. **Canopy Temperature Depression:** Canopy temperature ($^{\circ}\text{C}$) was observed between 13.00-15.00 hours with infrared thermometer, which was pointed at the sunlit leaves only from the top of canopy and interference by the exposed ground surface was avoided. Canopy temperature depression was estimated as difference of canopy temperature from mean air depression. Three observations were recorded in each plot and average worked out.
3. **Days to heading:** The heading days were counted from the date of sowing to 50 percent spike emergence per plot for each genotype.
4. **Plant height (cm):** Height of the five plants was measured in centimeters from ground level to tip of the spike at physiological maturity and average plant height was calculated.
5. **Peduncle length (cm):** At maturity the peduncle length of mother shoot was measured from last node (bearing the flag leaf) to the base of spike. Average peduncle length for each genotype was calculated.
6. **Grain weight per spike:** Each spike was threshed separately and grains of each spike were counted and weighed.
7. **Number of spikelets/spike:** The spikelets were counted on each spike taken from primary tiller of each plant at physiological maturity.

- 8. Number of grains/spike:** The spikes of primary tillers from each plot were taken after maturity. Individual spike was hand threshed in laboratory. All the grains from each spike were collected and counted separately.
- 9. Grain yield:** Grain yield in gram from each plot was recorded separately on electronic balance, and then average yield was calculated.
- 10. Total biomass (kg):** All plants from each genotype were harvested from ground level and weight of total produce was taken with weighing balance and average was worked out.
- 11. Heat susceptibility index:** Heat susceptibility index was calculated according to Fischer and Maurer (1978) as follows:

$$S = \frac{\left(1 - \frac{Y}{Y_p}\right)}{\left(1 - \frac{X}{X_p}\right)}$$

Where,

S = Heat susceptibility index

Y = Yield under stress

Y_p = Yield without stress

X = Mean yield over all cultivars under stress conditions

X_p = Mean yield over all cultivars under non- stress conditions.

- 12. Statistical analysis:** Mean and range was calculated. Data was analyzed by using simple 5x5 lattice design and randomized block design.

3.2 BIOCHEMICAL ANALYSIS AND QUALITY EVALUATION:

On the basis of field observations, total twenty five entries along with checks included in the state varietal trial MLHT I and MLHT II (2011-12) were selected for the further study of physicochemical, biochemical and quality characteristics:

MLHT I: GW433, HD3090, MP3353, WH1124, HI1571, PBW670, RAJ4250, WH1123, HD2864, HD2932, RAJ3765, RW3705, UAS320.

MLHT II: HD3040, HI8703, MP3304, HI8704, PBW639, WHD946, DBW14, DL788-2, HUW234, MP4010, NW2036, PBW373.

The grains of all these varieties were obtained from the Department of Plant Breeding Genetics, Punjab Agricultural University, Ludhiana. The samples were cleaned thoroughly to remove the extraneous matter and used for study of the following characteristics:

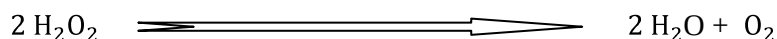
3.2.1 EXTRACTION AND ASSAY OF ANTIOXIDANT ENZYMES:

Antioxidant enzymes such as catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), peroxidase (POX) and glutathione reductase (GR) were extracted at 4°C to minimize denaturation.

3.2.1.1 Catalase (EC 1.11.1.6) (Chance and Maehly 1955)

A) Reaction

Catalase (CAT) is able to use one molecule of H_2O_2 as substrate or electron donor and another molecule of H_2O_2 as oxidant or electron acceptor. Catalase detoxifies H_2O_2 to H_2O and O_2 by following equation



B) Reagents

- 50mM Sodium phosphate buffer.
- H_2O_2 Solution (39mM): 0.2 ml of 30% H_2O_2 diluted to 50 ml with sodium phosphate buffer (pH7.5).

C) Extraction

100mg of tissue was homogenized in 2 ml of ice cold 50mM sodium phosphate buffer (pH7.5) containing 1% PVP using pre-chilled pestle-mortar. Homogenate was centrifuged at 10000 x g at 4°C for 15 minutes. Supernatant after centrifugation was used as enzyme extract for the estimation of CAT.

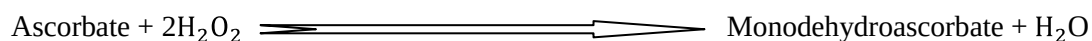
D) Assay

In spectrophotometric cuvette at 25°C, reaction volume of 3 ml containing 1.8 ml of sodium phosphate buffer of pH 7.5 and 0.2ml of enzyme extract was added. The reaction was initiated by adding 1 ml of H_2O_2 . Change in absorbance was recorded at 240 nm for 3 minutes at the interval of 30 seconds. Change in μmole of H_2O_2 per minute was calculated using molar extinction coefficient of H_2O_2 of 0.0394 mM^{-1} . Activity was expressed in μmole of H_2O_2 decomposed $\text{min}^{-1} \text{ g}^{-1} \text{ DW}$ and specific activity was expressed as μmole of H_2O_2 decomposed $\text{min}^{-1} \text{ mg}^{-1} \text{ protein}$.

3.2.1.2 Ascorbate peroxidase (EC 1.11.1.1) (Nakano and Asada 1987)

A) Reaction

Ascorbate peroxidase (APX) catalyses the conversion of H_2O_2 to H_2O at the expense of an electron acceptor ascorbate.



B) Reagents

- 50mM Sodium phosphate buffer (pH7.5)
- 0.5mM Ascorbic acid
- H_2O_2 Solution (39mM): 0.2 ml of H_2O_2 diluted to 50 ml with 50mM sodium phosphate buffer (pH7.5)

B) Extraction

100mg of tissue was homogenized in 2 ml of ice cold 50mM sodium phosphate buffer (pH7.5) containing 1% PVP using pre-chilled pestle-mortar. Homogenate was centrifuged at

10000 x g at 4°C for 15 minutes. Supernatant after centrifugation was used as enzyme extract for the estimation.

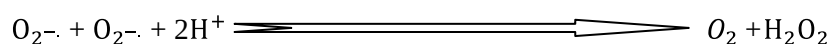
C) Assay

In spectrophotometric cuvette, reaction volume of 3 ml containing 1 ml of potassium phosphate buffer of pH 7.5, 0.8 ml of ascorbate, 0.2 ml of enzyme extract to which 1 ml of H₂O₂ was added. Change in absorbance was recorded at 290 nm in spectrophotometric cuvette at 25°C for 3 minutes at the interval of 30 seconds. The μmole of monodehydroascorbic acid (MDHA) formed per minute was calculated using molar extinction coefficient of 2.8mM⁻¹cm⁻¹. APX activity was expressed as μmole of MDHA formed min⁻¹g⁻¹ DW and specific activity was expressed as μmole of MDHA formed min⁻¹mg⁻¹ protein.

3.2.1.3 Superoxide dismutase (EC 1.15.1.1) (Marklund and Marklund 1974)

A) Reaction

SOD causes the conversion of superoxide anion to H₂O₂ in the presence of molecular O₂ hence scavenges toxic superoxide anion.



B) Reagents

- i. 6mM EDTA
- ii. 100mM Potassium phosphate buffer (pH 7.5)
- iii. 6mM Pyrogallol (Fresh solution was prepared for assay)
- iv. 100mM Tris – HCl buffer (pH 8.2)

C) Extraction

100mg of tissue was homogenized in 2 ml of ice cold 100mM potassium phosphate buffer (pH 7.5) containing 10mM β-mercaptoethanol, 1mM EDTA and 1% PVP.

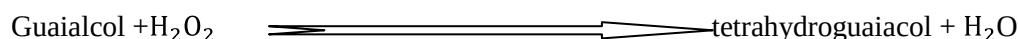
D) Assay

SOD was assayed at 25°C in spectrophotometric cuvette containing 1.5 ml of 100 mM Tris HCL buffer (pH 8.2), 0.5 ml of 6 mM EDTA, 1 ml of pyrogallol solution and 0.1 ml enzyme extract was added. Change in absorbance was recorded at 420 nm for 3 minutes at the interval of 30 seconds. Enzyme activity was expressed in SOD units where one SOD unit was defined as the amount of enzyme required to cause 50% inhibition of auto-oxidation of pyrogallol observed in blank. SOD activity was expressed as SOD units g⁻¹ DW. SOD specific activity was expressed as SOD units mg⁻¹ protein.

3.2.1.4 Peroxidase (EC 1.11.1.7) (Shannon *et al* 1996)

A) Reaction

Peroxidase catalyses the breakdown of H₂O₂ at the expense of electron acceptors such as ascorbate, quinones and cytochrome C. they are nonspecific in utilizing electron donor for oxidation H₂O₂.



B) Reagents

- i. 0.05 M Guaiacol prepared by using 100mM potassium phosphate buffer (pH 6.5)
- ii. 0.8 M H_2O_2

C) Extraction

100mg of tissue was homogenized in 2 ml of ice cold 0.1M potassium phosphate buffer (pH 7.5) containing 10mM β -mercaptoethanol, 1mM EDTA and 1% PVP.

D) Assay

The reaction mixture contained 3 ml of guaiacol, 0.1 ml of H_2O_2 to which 0.1 ml of enzyme extract was added. Change in absorbance at 470 nm was recorded in spectrophotometric cuvette at 25°C for 3 minutes at the interval of 30 seconds. Peroxidase activity was expressed in change in absorbance $\mu\text{mole min}^{-1}\text{g}^{-1}$ DW and specific activity was expressed as change in absorbance $\text{min}^{-1}\text{mg}^{-1}$ protein.

3.2.1.5 Glutathione reductase (EC 1.6.4.2) (Esterbauer and Grill 1978)

A) Reaction

Glutathione reductase catalyses the reduction of oxidized glutathione (GSSG) in a NADPH-dependant reaction.



B) Reagents

- i. 200mM Potassium phosphate buffer (pH 7.5)
- ii. 1.5mM MgCl_2
- iii. 0.2mM EDTA
- iv. 0.025mM NADPH
- v. 0.25mM Glutathione oxidized

C) Extraction

100mg of tissue was homogenized in 2 ml of ice cold 100mM potassium phosphate buffer (pH 7.5) containing 10mM β -mercaptoethanol, 1mM EDTA and 1% PVP.

D) Assay

GR was assayed in spectrophotometric cuvette at 25°C in a Reaction volume of 1 ml containing 0.2 ml of 200mM potassium phosphate buffer (pH 7.5), 0.1 ml of 0.2 mM EDTA, 0.1 ml of 1.5mM MgCl_2 , 0.2 ml of 0.025 mM NADPH, 0.2 ml of 0.25 mM glutathione oxidized (GSSG), All contents were mixed and reaction was started by adding 0.2 ml of enzyme extract. Change in absorbance was recorded for 3 minutes at the interval of 30 seconds at 340 nm. Decrease in nmole of NADPH min^{-1} was calculated using molar

extinction coefficient for NADPH ($6.22 \text{ mM}^{-1}\text{cm}^{-1}$). The glutathione reductase activity was expressed as nmole of NADP^+ formed $\text{min}^{-1}\text{g}^{-1}\text{DW}$.

3.2.2 EXTRACTION AND ESTIMATION OF HYDROGEN PEROXIDE (Sinha 1971)

A) Reagents

- i. 10mM Potassium phosphate buffer (pH 7.0)
- ii. 5% Potassium dichromate and glacial acetic acid (1:3 v/v)

B) Extraction

Tissue (300 mg) was homogenized in 2 ml of ice cold 10 mM potassium phosphate buffer (pH 7.0).the homogenate was centrifuged at 10000 rpm for 20 minutes and the supernatant was collected and used for estimation of H_2O_2 content.

C) Estimation

For estimation supernatant was diluted to 2 ml with 10 mM potassium phosphate buffer (pH 7.0). 2 ml of 5% potassium dichromate and glacial acetic acid (1:3 v/v) were added to the diluted supernatant. The reaction mixture was then filtered using Whatman filter paper no. 1 and absorbance was read at 570 nm against the reagent blank. The quantity of H_2O_2 was determined from the standard curve prepared by taking different concentrations of H_2O_2 ranging from 20 to 100 μmoles . H_2O_2 content was expressed as $\mu\text{moles g}^{-1}\text{DW}$.

3.2.3 EXTRACTION AND ESTIMATION OF MALONDIALDEHYDE (Okhawa et al 1979)

A) Reagents

- i. 5% Trichloroacetic acid
- ii. Trichloroacetic acid-thiobarbituric acid solution: 20% (w/v) trichloroacetic acid containing 0.5% (w/v) thiobarbituric acid

B) Extraction

Tissue (200 mg) was homogenized in 2 ml of 5% trichloroacetic acid (TCA) and the homogenate was centrifuged at 10000 rpm for 15 minutes at room temperature. Supernatant was taken for malondialdehyde estimation.

C) Estimation

The supernatant was mixed with an equal volume of 20% (w/v) TCA containing 0.5% thiobarbituric acid (TBA). The mixture was heated at 95°C for 30 minutes, cooled in ice and centrifuged at 10000 rpm for 10 minutes. Absorbance of the supernatant was measured at 532 nm and corrected for non specific absorbance by subtracting the absorbance taken at 600 nm. MDA contents were calculated using an extinction coefficient of $155 \text{ mM}^{-1}\text{cm}^{-1}$. The results were expressed as n mol MDA g^{-1}DW .

3.2.4 Statistical analysis: Mean $\pm$ SD was calculated. Data was analyzed using completely randomized design.

3.2.5 QUALITY EVALUATION:

3.2.5.1 Grain Quality Characteristics:

- 1. Grain Appearance Score:** It was evaluated subjectively out of a maximum Score of ten giving due weightage to the grain size, shape, colour and luster.
- 2. Test weight (kg/hl):** This was determined using the apparatus developed by the Directorate of Wheat Research, Karnal, which employs a standard container of 100 ml capacity (Mishra *et al* 1998). The grains were weighed and the test Weight expressed in kg/hl.
- 3. Grain hardness (kg/grain):** The grain hardness was measured by using the grain hardness tester supplied by M/S Ogawa Seiki Co. Ltd., Japan by crushing ten grains one by one selected randomly from the lot. The mean force (kg) required to crush the grain was recorded.
- 4. Grain Plumpness:** 100 gm of grains were separated according to the grain diameters (2.2mm, 2.5mm, 2.8mm and 2.8mm) using grain sorter (Sortimate, Germany) fitted with respective sized meshes. The grains of different diameters were collected and then weighed on an electronic balance and expressed in percentage.
- 5. Phenol Test:** The phenol reaction of the wheat genotypes was determined by soaking 15-20 grains of each sample in distilled water for 15-16 hours in Petri plates. After that the water is drained off and 1 per cent solution of phenol was added to the grains so that only three fourth of the grain is covered by the solution. The Petri plates are covered and kept for 4 hour. After 4 hours the phenol solution is also drained off and the grains are dried of filter paper for 30 minutes. A subjective score (out of 10) is given to each genotype based on the colour after drying. Higher score will be given to the grains with darker intensity of the colour.
- 6. Protein Content:** The grain protein content was estimated using the whole grain analyzer infratec 1241 supplied by M/S Foss Analytical AB, Sweden, The instrument uses the near infrared light transmitted through the grains. The grain samples are scanned in the range of 850 to 1050 nm with bandwidth of 7 nm and there are 100 data points per scan. The results are displayed as percent protein content.
- 7. SDS Sedimentation Value:** The SDS Sedimentation values of wholemeal samples were determined by employing the method given by Axford *et al* (1979). A wholemeal sample weight of 6g and a rest period of 20 min were employed. On the basis of SDS Sedimentation values, the following classification of wheat was done:

Sedimentation Value (cc)	Wheat Class
Below 48	Weak
48-68	Medium Strong
Above 68	Strong

8. Gluten Content and Index (%): The gluten content and index values were evaluated using Glutomatic 2100 system supplied by M/S Perten, Germany. The instrument employs a 10g sample of whole meal using the AACC method. The wet gluten content was calculated from the weight of the two fractions obtained after centrifuging for gluten index determination. The wet gluten was then dried in the Glutork gluten drier and the weight expressed as percent. The gluten index is expressed as the percent wet gluten retained inside the centrifuge cassette. On the basis of dry gluten content, the wheat samples were classified as given below:

Dry Gluten Content (%)	Class of Wheat
7-9	Low gluten
>9	High gluten

9. Starch Pasting Characteristics: The starch pasting characteristics were estimated with Starch master using the following procedure: Switch on the instrument and allow it to warm up for 30 min prior to the experiment. Weigh 4.0 g of wholemeal in a canister and add 25.0 ml distilled water into the canister. Place paddle into the canister and vigorously jog the blade through the sample up and down 10 times or until it mixes uniformly. Insert the canister into the pre-adjusted instrument using the standard profile given below:

Time	Type	Value
00:00:00	Speed	960rpm
00:00:00	Speed	160rpm
00:00:00	Temp	50°C
00:01:00	Temp	50°C
00:04:42	Temp	95°C
00:07:12	Temp	95°C
00:11:00	Temp	50°C

Idle Temperature : 50 ± 1°C

End of Test : 13 min

Time between readings : 4 Sec

Initiate the measurement cycle by depressing the motor tower of the instrument. Remove the canister on completion of test and discard. Note down the gelatinization temperature, peak viscosity, break down and hold viscosity, setback and final viscosity from the instrument.

3.2.6. ESTIMATION OF TOTAL SUGARS:(Dubios *et al* 1956)

A) Reagents

3.2.7. 95% Sulphuric acid

3.2.8. 5% Phenol (w/v)

B) Extraction

Crush 100 mg of tissue in a pestle mortar and free sugars were extracted two times with 15 ml each of 80 percent ethanol and 70 percent ethanol by keeping the tubes, with water condenser, in a boiling water bath for 20 minutes. Supernatant is pooled and ethanol from the pooled extracts was evaporated. The extracts after dilution with water were used for the estimation of free sugars.

C) Estimation

Take 1 ml of diluted sugar extract and add 1 ml of 5 percent phenol. Mix and add 5 ml of concentrated H₂SO₄. Read absorbance of the colour formed after 30 min at 490 nm. Calculate the concentration of total sugars of the sample on the basis of the standard curve prepared from glucose standard (10-100ug).

3.2.8 Statistical analysis

Mean and range was calculated. Data was analyzed using completely randomized design.

CHAPTER IV

RESULTS AND DISCUSSION

The fifty genotypes from MLHT I and MLHT II trials were studied for various physiological parameters like chlorophyll content, canopy temperature depression, plant height and grain weight. The fourteen entries along with eleven checks were selected on the basis of physiological results and studied for biochemical and quality characteristics such as antioxidant enzyme (Ascorbate peroxidase, Superoxide dismutase, Glutathione reductase, Peroxidase and Catalase), SDS-Sedimentation test, proteins content, test weight, grain hardness and phenol reaction test. Correlation was also worked out between different quality characteristics. The results of the study are discussed as follows:

4.1 Physiological parameters: mean performance

4.1.1 Chlorophyll content

The chlorophyll content in leaves was determined using SPAD before 15 days of anthesis, at the level of anthesis and after 15 days of anthesis for both the trials MLHT I and - MLHT II (Table 1a and 1b). In MLHT I, the chlorophyll content ranged from 43.3 to 56.8 under timely sown conditions and 45.6 to 65.7 under late sown conditions before 15 days of anthesis. The chlorophyll content of timely sown conditions ranged from 32.6 to 57.4 at the level of anthesis and for late sown it ranged from 33.0 to 51.2. Chlorophyll of timely sown conditions after 15 days of anthesis ranged from 18.6 to 42.1 and for late sown conditions it had reported 22.0 to 51.6. Genotypes GW 431, HD 3096 had higher chlorophyll under timely sown conditions and genotypes HD 2864, HD 3091, HD 3095 and UAS 320 had higher chlorophyll under late sown conditions before 15 days of anthesis. Genotypes PBW 670, and RSP 561 had high chlorophyll under timely sown and genotypes GW 433 and HD 3095 had high chlorophyll under late sown conditions at the level of anthesis. Genotypes GW 433, HD 3095 and RW 3705 had high chlorophyll under timely sown and genotypes DBW 90 and HD 3095 had high chlorophyll under late sown conditions after 15 days of anthesis.

Genotypes GW 433, HD 3095, NIAW 1689 and UAS 320 were found to be tolerant under heat stress due to higher chlorophyll content. Genotypes GW 432, HUW 234 were found to be susceptible due to decrease in chlorophyll content.

For trial MLHT II, the chlorophyll content ranged from 32.8 to 57.8 under timely sown conditions and 47.9 to 65.0 under late sown conditions at the level before 15 days of anthesis. The chlorophyll ranged from 35.2 to 56.4 for timely sown and 32.6 to 53.5 for late sown conditions at the level of anthesis and after 15 days of anthesis the chlorophyll content of timely sown ranged from 22.3 to 43.7 and for late sown it ranged from 23.5 to 40.1.

Table 1a: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

Genotype	Chlorophyll before 15 days of anthesis (%)		Chlorophyll at anthesis (%)		Chlorophyll at 15 days after anthesis (%)	
	TS	LS	TS	LS	TS	LS
DBW90	47.1±3.75	47.9±4.23	37.2±3.99	40.1±2.16	18.6±3.08	46.9±2.26
DPW621-50	52.7±2.39	53.7±2.03	50.7±2.21	45.4±2.02	24.9±2.12	36.7±2.02
GW431	55.6±4.56	54.8±4.56	53.4±5.62	46.2±4.51	35.9±5.07	40.8±4.59
GW432	52.3±5.28	47.3±4.06	43.5±4.67	33.4±4.02	28.8±4.35	22.0±4.23
GW433	48.7±4.30	51.6±3.56	32.6±3.93	50.3±2.98	28.5±3.46	41.4±2.756
HD2864	53.3±3.41	65.7±2.46	44.6±2.94	40.7±2.00	29.5±2.47	44.0±2.58
HD2932	53.3±1.14	53.9±1.02	53.0±1.08	48.1±1.02	36.4±1.05	36.5±1.06
HD3090	53.1±1.87	54.2±1.57	51.4±1.72	43.0±2.05	30.6±1.89	37.5±1.78
HD3091	46.8±5.79	55.7±4.58	49.1±5.19	44.6±5.29	30.7±5.24	34.1±5.28
HD3095	46.0±5.64	55.6±5.12	46.3±5.38	51.2±4.98	42.1±5.18	51.6±5.19
HD3096	56.8±3.32	54.8±3.25	49.0±3.29	47.9±3.54	34.2±3.41	36.3±3.24
HI1563	49.2±1.29	54.1±1.09	53.1±1.19	34.6±1.24	35.8±1.22	22.7±1.24
HI1571	51.2±4.35	54.5±3.49	51.9±3.92	50.5±3.57	31.4±3.75	45.9±3.48
HI8703	50.2±3.56	45.6±3.54	34.7±3.55	41.9±2.75	23.4±3.15	39.2±3.19
HUW234	50.4±4.65	49.4±3.24	46.2±3.95	33.0±3.48	31.8±3.71	31.7±2.49
MP3353	47.1±4.15	55.3±2.45	45.4±4.12	41.2±4.29	32.3±4.21	35.6±4.06
NIAW1689	48.7±2.62	52.5±3.25	44.7±1.51	48.5±0.20	27.5±0.86	36.0±1.05
PBW670	50.5±2.82	51.0±2.15	54.8±1.61	46.0±2.12	38.8±0.91	28.9±1.24
RAJ3765	52.7±2.39	53.3±4.56	52.8±1.40	46.8±1.02	25.7±0.80	38.7±0.94
RAJ4250	48.8±3.41	55.0±2.49	47.8±1.91	45.8±1.56	30.6±1.05	33.1±1.02
RSP561	47.8±6.26	53.2±5.26	57.4±3.33	41.1±2.42	32.8±1.77	35.4±1.81
RW3705	43.3±5.23	49.6±2.45	46.1±2.82	39.1±1.05	36.7±1.51	24.6±1.42
UAS320	43.3±4.29	56.5±1.25	41.2±2.35	49.3±1.42	28.5±1.27	44.8±1.34
WH1123	49.5±1.26	52.8±2.78	52.3±0.83	41.8±2.46	34.4±0.52	33.7±0.59
WH1124	47.2±2.48	52.8±2.89	52.8±1.44	41.8±1.89	34.5±0.82	23.3±0.94
Range	43.3-56.8	45.6-65.7	32.6-57.4	33.0-51.2	18.6-42.1	22.0-51.6
Mean	49.9	53.2	47.4	43.7	31.2	36.5
CD at 5%	Replications TS=5.95 Treatments TS=6.13			Replications LS=2.82 Treatments LS=8.14		

Values are mean±SD of five replicates

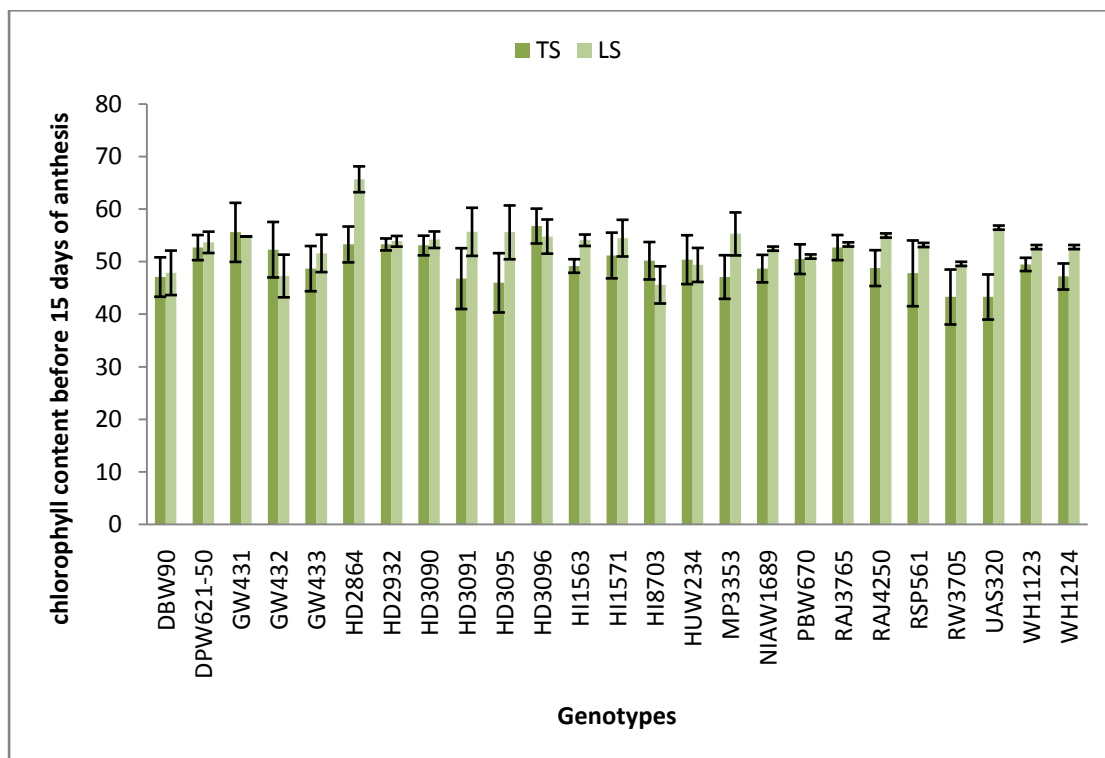


Fig 1a: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

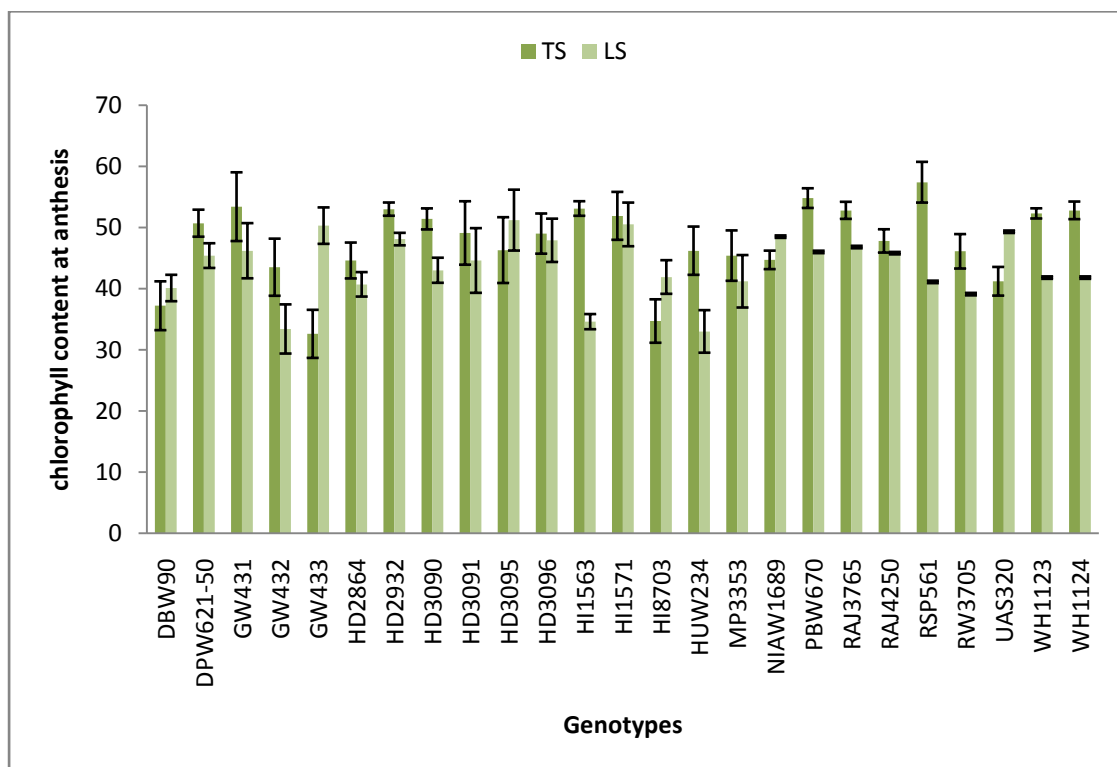


Fig 1b: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

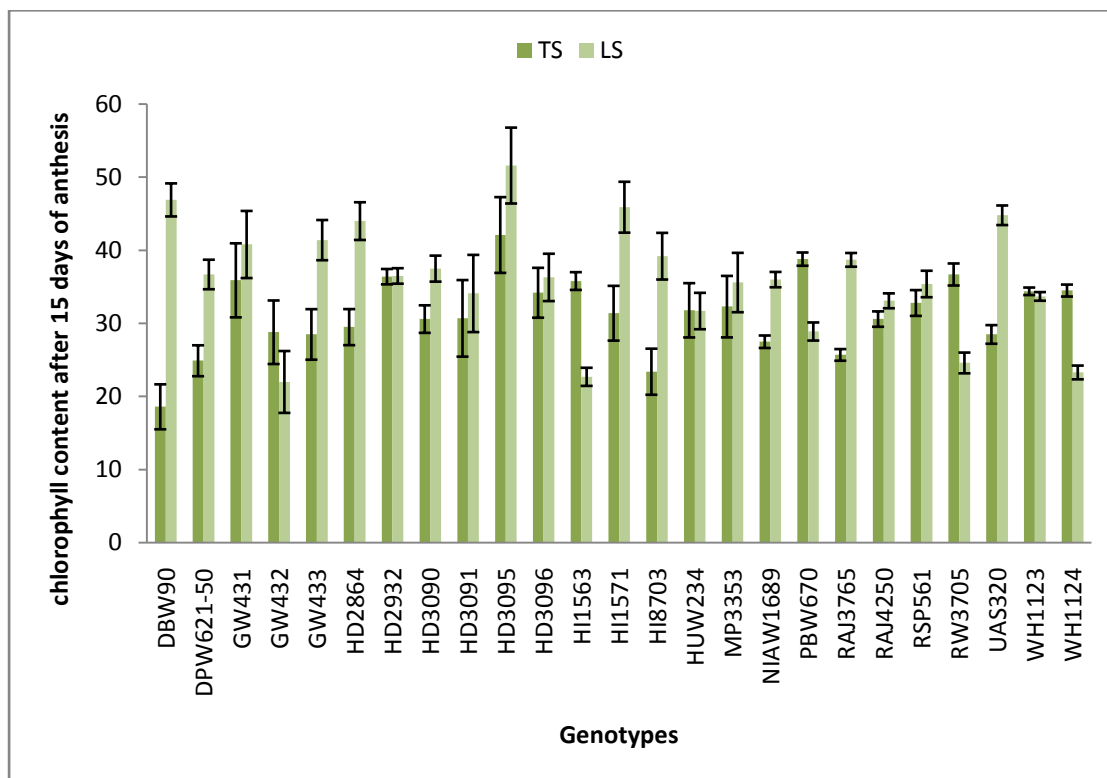


Fig 1c: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

The chlorophyll content of genotypes HD 3040, MP 4010, NIAW 34 and PDW 322 found to be higher for timely sown conditions before 15 days of anthesis.

For late sown conditions genotypes PDW 322, NW 2036, PBW 590 and UAS 320 had higher chlorophyll before 15 days of anthesis. Genotypes HD 3040, MP 4010, NW 2036, PBW 639 and RAJ 4083 had higher chlorophyll under timely sown conditions at the level of anthesis and genotype NW 2036 had relatively greener leaves under late sown conditions at the level of anthesis.

Chlorophyll content of timely sown conditions of genotypes MP 4010 and NW 2036 had higher value after 15 days of anthesis and PBW 373 had higher chlorophyll for late conditions after 15 days of anthesis.

Genotypes HD 2864 and PDW 322 were found to be tolerant under heat stress. Genotypes HD 2932 had no chlorophyll change. DL 788-2 and MP 4010 were found to be susceptible. The chlorophyll content found to be significant ($p < 0.05$) under both the trials for both timely and late sown conditions.

Table 1b: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

Genotype	Chlorophyll before 15 days of anthesis (%)		Chlorophyll at anthesis (%)		Chlorophyll after 15 days of anthesis (%)	
	TS	LS	TS	LS	TS	LS
AKAW4210-6	47.4±2.03	52.0±2.27	45.4±2.43	32.2±1.23	36.6±1.69	29.9±1.28
DBW14	51.0±1.70	51.4±1.52	49.8±1.61	34.8±1.51	34.5±1.56	25.5±1.51
DL788-2	48.5±3.31	47.9±1.00	50.3±3.31	46.1±2.76	38.5±3.03	33.4±2.80
HD2864	48.2±3.14	56.7±2.53	35.2±2.84	35.5±2.51	23.3±2.67	27.5±2.62
HD2932	49.3±2.65	52.4±2.28	52.7±2.47	36.8±1.99	22.3±2.23	26.3±1.88
HD3040	55.4±2.21	53.5±1.73	54.5±1.97	41.5±1.50	26.3±1.73	30.9±1.79
HI1563	52.7±1.07	50.9±1.01	52.6±1.04	34.4±1.01	24.4±1.03	23.6±1.03
HI1571	52.2±1.44	53.4±1.29	56.4±1.36	41.6±1.53	36.4±1.44	28.8±1.39
HI8703	32.8±3.40	52.4±2.79	39.3±3.09	35.2±3.15	27.8±3.12	23.5±3.14
HI8704	42.4±3.32	50.3±3.06	46.6±3.19	33.7±2.99	22.7±3.09	25.9±3.10
HUW234	52.4±2.16	53.6±2.13	51.2±2.14	46.9±2.27	37.5±2.21	33.1±2.12
LOK62	53.1±1.15	57.3±1.05	48.3±1.10	47.2±1.12	33.6±1.11	29.6±1.12
MP3304	48.6±2.68	56.5±2.25	51.1±2.46	46.1±2.29	23.7±2.37	32.8±2.24
MP4010	57.8±2.28	57.0±2.27	53.3±2.28	51.9±1.88	42.8±2.08	36.9±2.10
NIAW34	55.0±2.83	52.3±2.12	49.9±2.47	45.6±2.24	27.2±2.36	34.1±1.75
NW2036	52.7±2.58	62.3±2.55	53.6±2.56	53.5±2.65	43.7±2.60	33.9±2.53
PBW373	49.2±1.81	58.0±1.72	49.2±1.26	44.9±1.47	35.1±0.93	40.1±1.03
PBW590	54.4±1.91	62.6±1.58	52.7±1.31	36.0±1.37	24.8±0.95	33.6±1.12
PBW639	51.3±1.70	52.2±1.78	53.5±1.20	41.0±1.18	40.7±0.90	32.6±0.97
PDW322	54.5±2.21	65.0±2.51	43.8±1.45	43.9±1.03	29.5±1.03	30.1±1.01
RAJ4083	51.2±3.63	59.5±3.23	53.9±2.17	44.9±1.98	37.1±1.38	30.6±1.41
UAS320	48.0±3.12	62.2±3.12	52.5±1.91	46.1±1.73	35.7±1.25	27.7±1.21
UAS428	49.3±2.65	56.8±2.27	42.7±1.67	34.4±2.24	35.1±1.14	25.2±1.17
WH1021	51.3±1.13	52.8±1.02	50.6±0.92	34.5±0.97	31.4±0.76	26.6±0.80
WHD946	46.8±1.74	58.3±1.73	47.0±1.22	32.7±1.13	33.0±0.91	27.5±0.97
Range	32.8-57.8	47.9-65.0	35.2-56.4	32.2-53.5	22.3-43.7	23.5-40.1
Mean	50.2	55.5	49.4	40.8	32.1	30.0
CD at 5%	Replications TS=7.32 Treatments TS=7.40			Replications LS=6.13 Treatments LS=6.22		

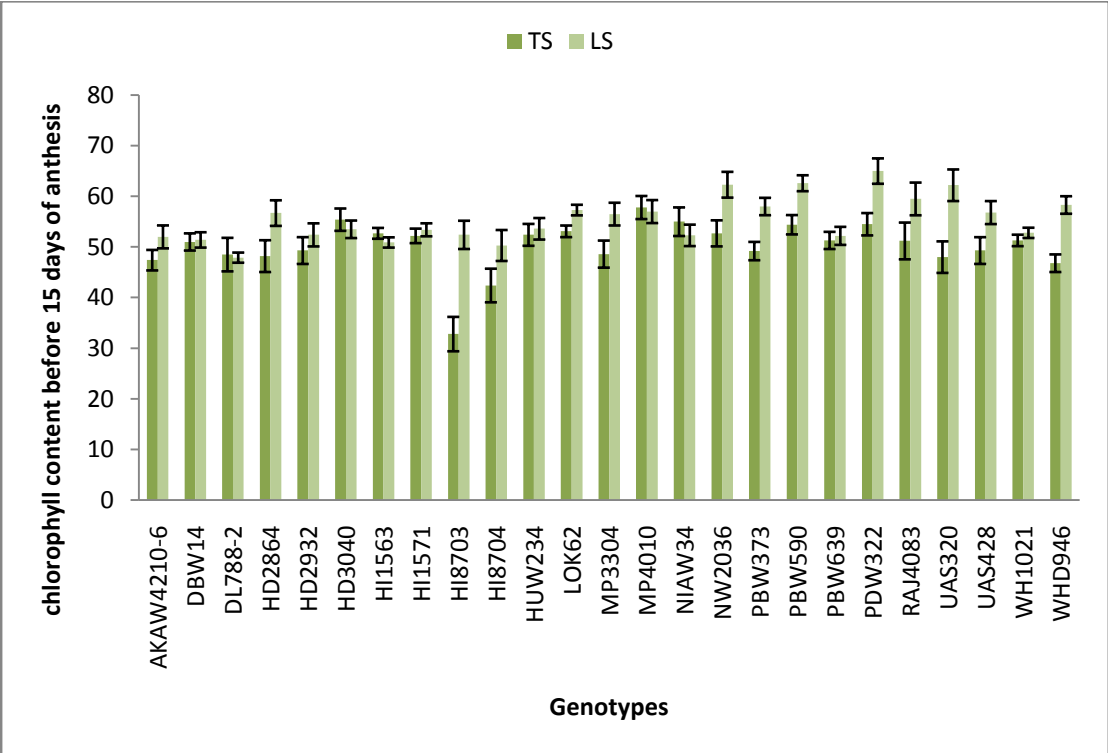


Fig 1d: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

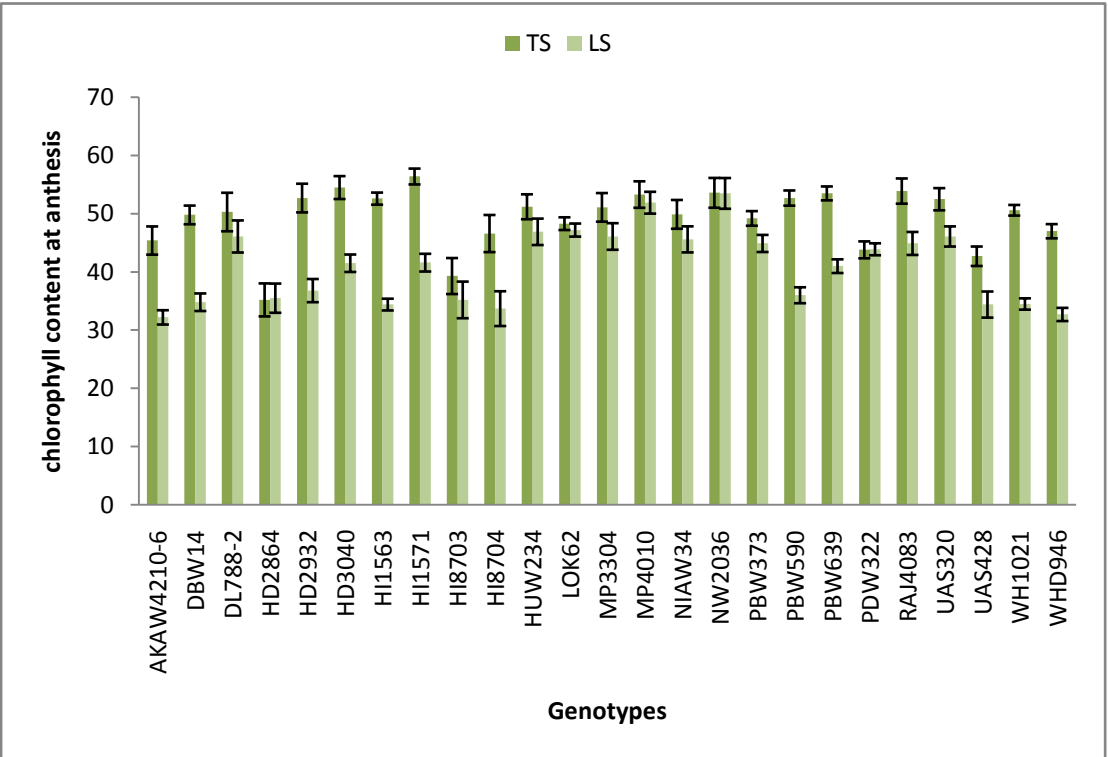


Fig 1e: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

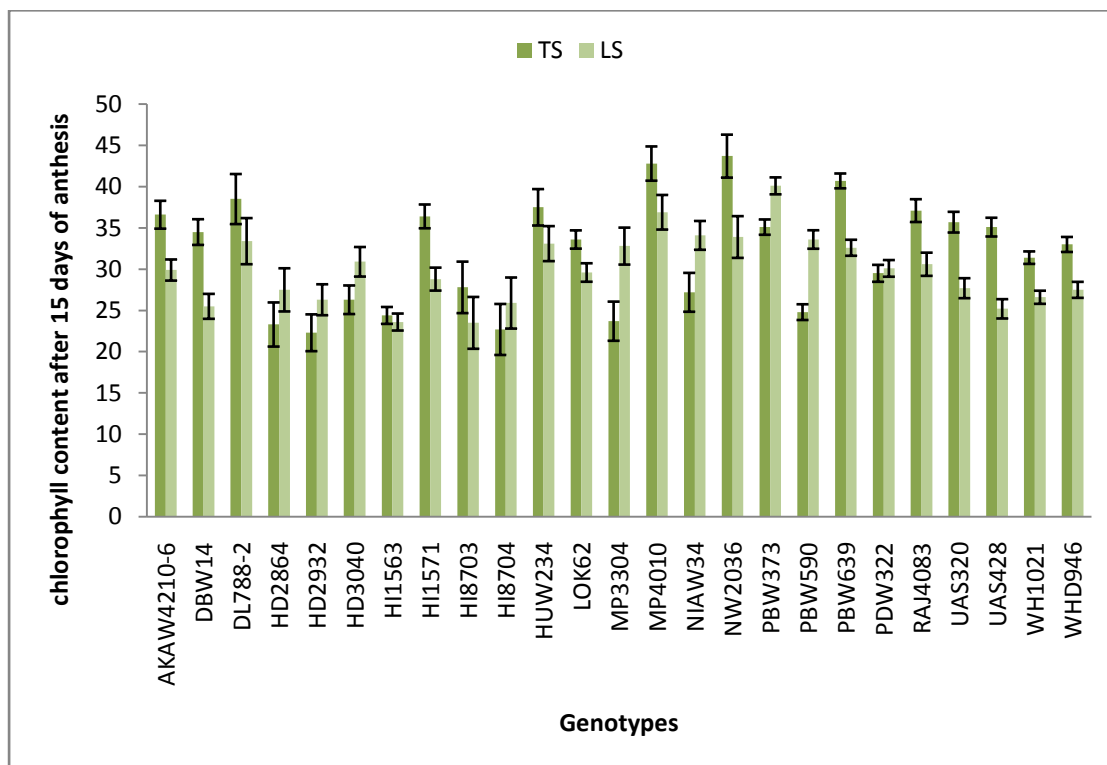


Fig 1f: Leaf chlorophyll (SPAD) measured at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

Chlorophyll loss (Fig 1a-1f) was observed between the chlorophyll content before 15 days to anthesis and after 15 days of anthesis and chlorophyll loss was more in late sown conditions in both the trials MLHT I and MLHT II indicating highly injurious effect of the high temperature on current photosynthesis. High temperature decreases the rate of photosynthesis by reducing chlorophyll content of leaves. Results were in accordance with Al-Khatib and Paulson (1990), who observed that mean photosynthetic rate and chlorophyll fluorescence decrease at high temperature.

4.1.2 Canopy temperature depression (CTD)

Canopy Temperature Depression (CTD) is usually expressed as canopy temperature minus air temperature. Canopy temperature depression was measured under timely and late sown conditions before 15 days of anthesis, at the level of anthesis and after 15 days of anthesis depicted in table 2a and 2b. In MLHT-I, the CTD ranged from 24.4 to 28.5 °C under timely sown conditions and 23.0 to 29.0 °C under late sown conditions before 15 days of anthesis. At the level of anthesis CTD ranged from 21.6 to 31.2°C under timely sown and 27.8 to 30.9 °C under late sown conditions. CTD ranged from 20.2 to 32.8°C under timely sown and 28.0 to 32.3 °C under late sown conditions, after 15 days of anthesis.

In MLHT-II, the canopy temperature depression ranged from 21.7 to 34.4°C under timely sown conditions and 22.4 to 29.8°C under late sown conditions before 15 days of anthesis and it ranged from 28.8 to 32.3°C under timely sown conditions and 27.0 to 30.8°C under late sown condition at the level anthesis. It ranged from 22.3 to 34.1°C under timely sown conditions and 21.7 to 34.3°C under late sown conditions after 15 days of anthesis. Genotypes MP 4010, NIAW 34, PBW 590, PBW 639, PDW 322 had higher CTD before 15 days of anthesis under timely sown conditions and varieties DBW 14, HI 1563, HI 1571 and HUW 234 had higher CTD under late sown conditions before 15 days of anthesis. At the level of anthesis varieties HI 8703, LOK 62, NIAW 34, PBW 37 and PDW 322 had higher CTD under timely sown conditions and varieties AKAW 4210-6, HD 2864, HI 8703, MP 3304, PBW 639, RAJ 4083, WH 1021 and WHD 946 had higher CTD under late sown conditions.

The varieties DL 788-2, HD 2864, HD 2932, PBW 322, UAS 428 and WH 1021 had higher CTD under timely sown conditions and varieties DL 788-2, HD 3040, HI 8704, MP 4010, NIAW 34, PBW 590, PBW 639 and WHD 946 had higher CTD under late sown conditions at 15 days after anthesis level.

Genotypes DBW 14 and MP 3304 were found to be tolerant under heat stress. Genotypes AKAW- 4210-6, DL 788, HD 2932 and MP 3304 had no change in CTD. Genotypes HD 2864, UAS 320, UAS 428 WH 1021 were found to be susceptible. Canopy temperature depression was increased under late sown conditions. The CTD was found to be significant ($p < 0.05$) for the trial MLHT I.

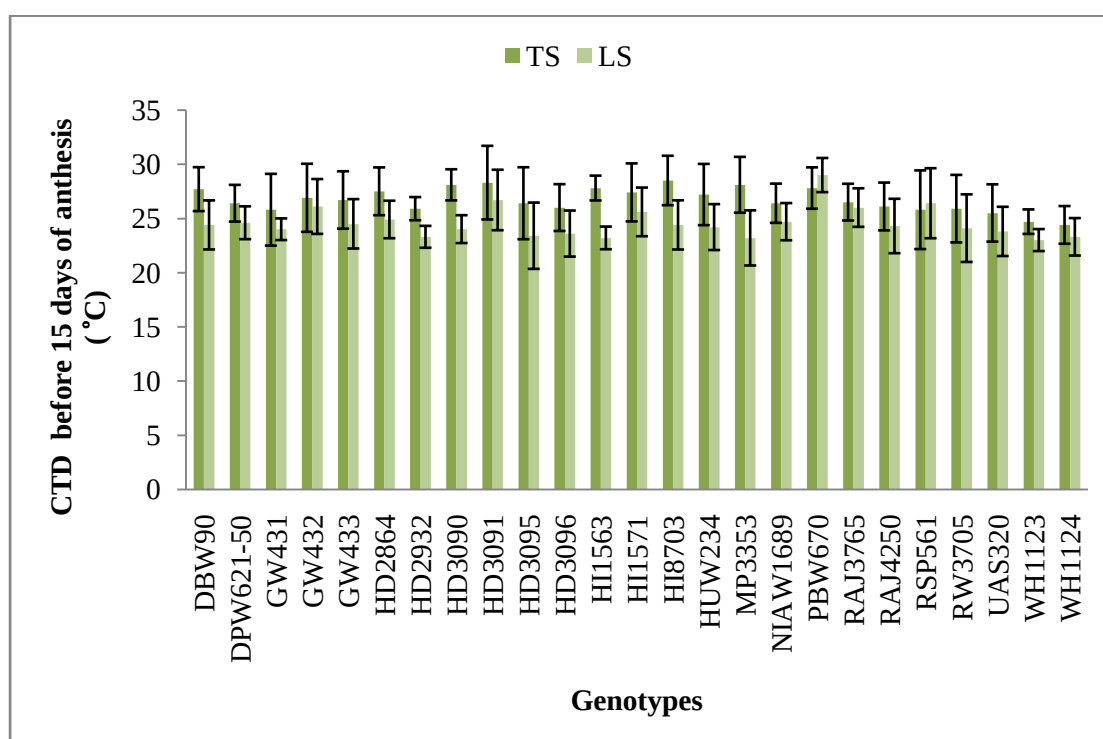


Fig 2a: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT

Table 2a: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

Genotype	CTD Before 15 days of anthesis (°C)		CTD at anthesis (°C)		CTD after 15 days of anthesis (°C)	
	TS	LS	TS	LS	TS	LS
DBW90	27.7±1.31	24.4±1.43	29.5±1.51	30.7±0.92	30.7±1.14	30.7±0.94
DPW621-50	26.4±1.15	24.6±1.06	26.5±1.10	29.1±1.06	32.3±1.08	30.0±1.06
GW431	25.8±1.96	24.0±0.80	28.6±1.96	29.6±1.68	30.3±1.82	28.0±1.70
GW432	26.9±1.87	26.1±1.57	29.7±1.72	30.5±1.56	31.8±1.64	32.3±1.61
GW433	26.7±1.63	24.5±1.44	30.6±1.53	28.8±1.30	32.2±1.41	28.3±1.24
HD2864	27.5±1.40	24.9±1.17	29.8±1.28	27.8±1.05	31.1±1.17	29.4±1.20
HD2932	25.9±0.84	23.3±0.81	30.9±0.82	28.6±0.81	31.1±0.81	29.0±0.82
HD3090	28.1±1.02	24.0±0.94	30.3±0.98	29.1±1.06	32.4±1.02	30.1±1.00
HD3091	28.3±2.00	26.7±1.70	31.1±1.85	29.3±1.87	30.1±1.86	30.8±1.87
HD3095	26.4±1.96	23.4±1.83	29.8±1.90	28.0±1.80	30.3±1.85	28.0±1.85
HD3096	26.0±1.38	23.6±1.36	29.2±1.37	28.2±1.44	29.2±1.40	29.1±1.36
HI1563	27.8±0.87	23.2±0.82	29.7±0.85	30.4±0.86	31.6±0.85	32.1±0.86
HI1571	27.4±1.64	25.6±1.42	27.1±1.53	28.9±1.44	31.7±1.49	31.3±1.42
HI8703	28.5±1.44	24.4±1.44	21.6±1.44	29.4±1.24	28.7±1.34	29.4±1.35
HUW234	27.2±1.71	24.2±1.36	30.3±1.54	30.1±1.42	32.1±1.48	31.0±1.17
MP3353	28.1±1.59	23.2±1.57	30.9±1.58	29.8±1.62	32.8±1.60	30.7±1.57
NIAW1689	26.4±1.21	24.7±1.16	29.7±0.93	28.3±1.04	20.2±0.76	28.6±0.81
PBW670	27.8±1.26	29.0±1.09	29.4±0.95	28.7±0.99	28.7±0.78	29.4±0.86
RAJ3765	26.5±1.15	26.0±1.19	30.6±0.90	30.3±0.89	32.8±0.75	31.2±0.79
RAJ4250	26.1±1.40	24.3±1.56	29.9±1.03	28.9±0.81	30.0±0.81	30.1±0.81
RSP561	25.8±2.12	26.4±1.92	30.1±1.38	29.6±1.29	32.5±0.99	31.0±1.00
RW3705	25.9±1.86	24.1±1.86	31.2±1.25	29.5±1.17	30.3±0.93	29.1±0.91
UAS320	25.5±1.62	23.8±1.44	31.1±1.14	30.9±1.42	30.4±0.87	28.6±0.89
WH1123	24.7±0.87	23.0±0.81	30.6±0.76	29.0±0.79	31.1±0.68	28.2±0.70
WH1124	24.4±1.17	23.3±1.17	29.6±0.91	29.5±0.87	31.0±0.76	29.8±0.79
Range	24.4-28.5	23.0-29.0	21.6-31.2	27.8-30.9	20.2-32.8	28.0-32.3
Mean	26.7	24.5	29.5	29.3	30.0	29.8
CD at 5%	Replications TS=0.58 Treatments TS= 1.67			Replications LS=1.58 Treatments LS=1.62		

Values are mean±SD of three replicates

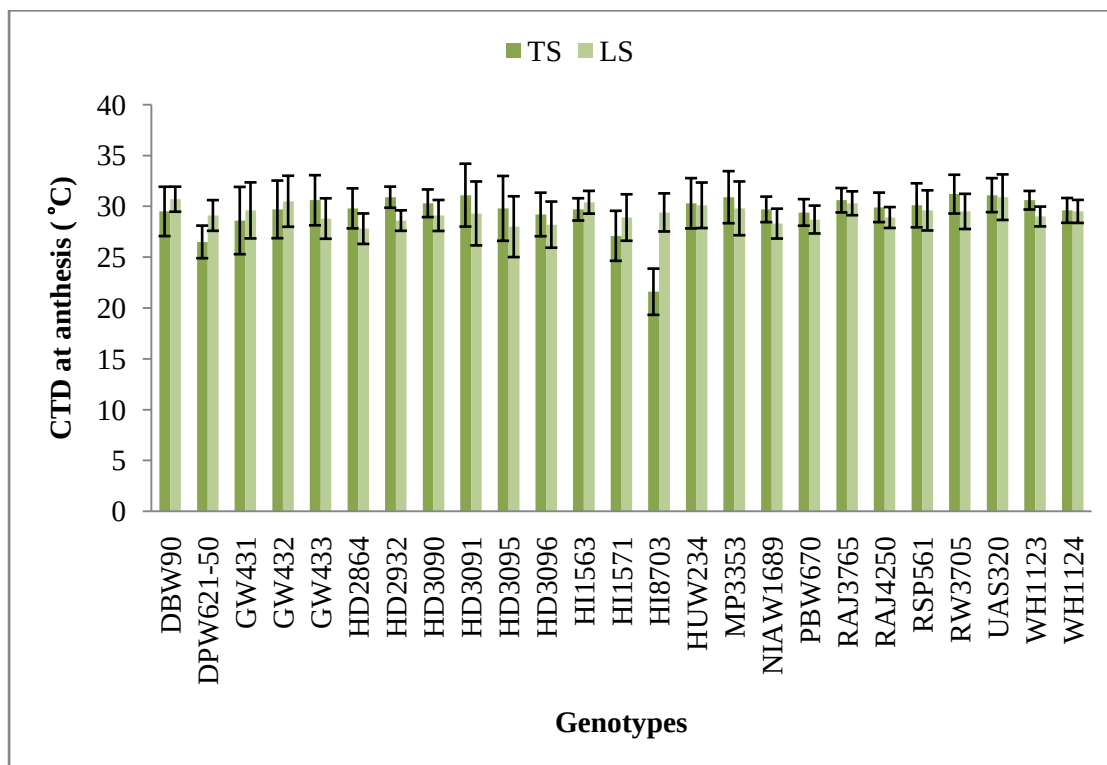


Fig 2b: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

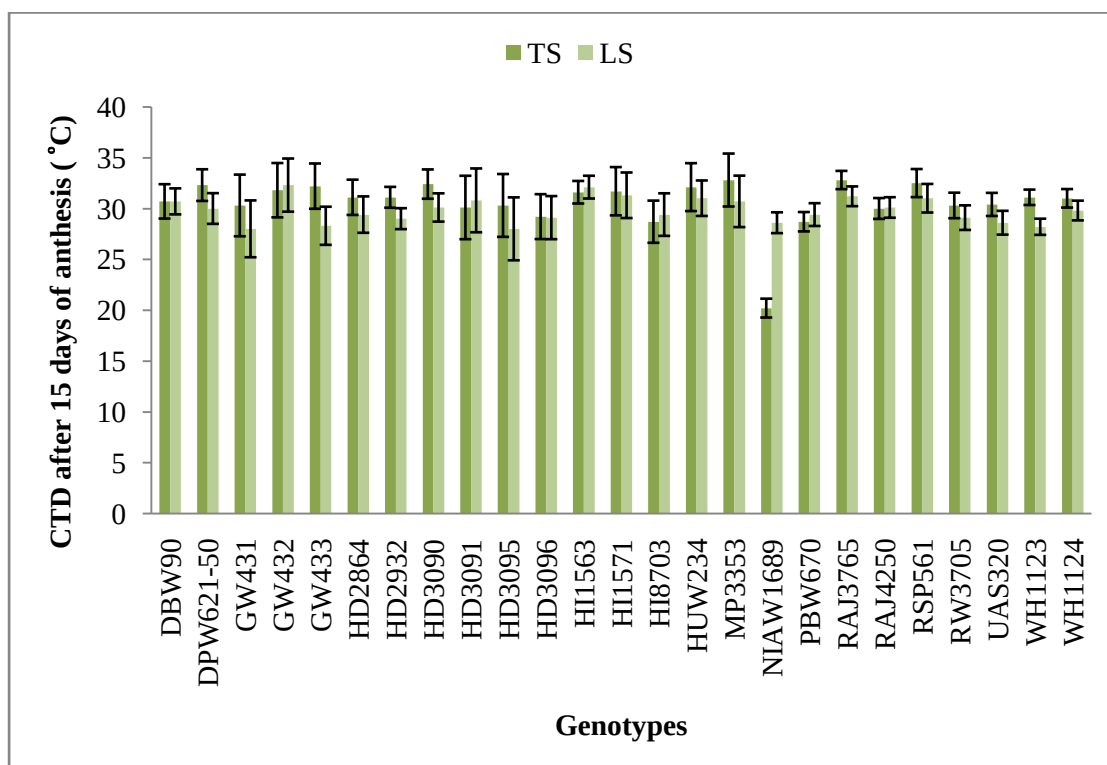


Fig 2c: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT I

Genotypes HI 8703, HD 3090, HD 3091, HI 1563 and MP 3353 had higher CTD for timely sown and genotypes HD 3091, PBW 670, RAJ 3765 and RSP 561 had higher for late sown conditions before 15 days of anthesis. Genotypes HD 3091, RW 3705 and UAS 320 had higher CTD for timely sown and genotypes DBW 90, GW 433 and UAS 320 had higher CTD for late sown at the level of anthesis. Genotypes GW 433, HD 3090, HUW 234, RAJ 3765 and RSP 561 had higher CTD for timely sown and genotypes GW 432, HI 1571 and HI 1563 had higher CTD for late sown after 15 days of anthesis.

Genotypes GW 432 and HI 1563 were found to be tolerant under heat stress due to higher CTD. Genotypes GW 432, HD 3091, PBW 670, RAJ 4250 and RAJ 3765 had no change in CTD. Genotypes GW 433, HD 2864, HD 3090, HD 3095, HD 3096, HUW 234, MP 3353, RW 3705, UAS 320, HD 2932, WH 1123 and WH 1124 were found to be susceptible.

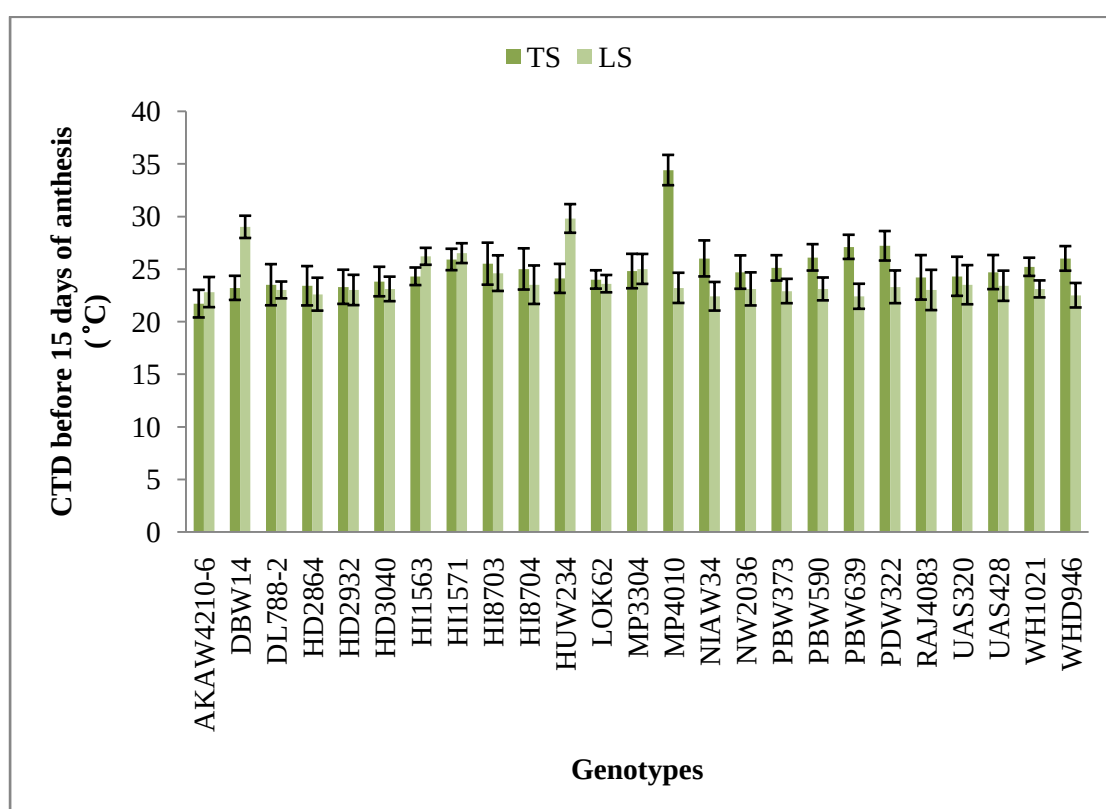


Fig 2d: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

Table 2b: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

Genotype	CTD before 15 days of anthesis (°C)		CTD at anthesis (°C)		CTD after 15 days of anthesis (°C)	
	TS	LS	TS	LS	TS	LS
AKAW4210-6	21.7±1.31	22.8±1.37	29.2±1.41	30.0±1.11	31.9±1.12	31.0±1.02
DBW14	23.2±1.22	29.0±1.18	28.9±1.20	29.4±1.18	31.3±1.18	31.3±1.12
DL788-2	23.5±1.63	23.0±1.05	28.9±1.63	29.8±1.49	32.3±1.50	32.7±1.59
HD2864	23.4±1.59	22.6±1.43	30.5±1.51	30.2±1.43	34.1±1.45	30.9±1.52
HD2932	23.3±1.46	23.0±1.37	29.9±1.42	29.2±1.30	32.7±1.27	31.5±1.27
HD3040	23.8±1.35	23.1±1.23	30.3±1.29	29.4±1.18	31.3±1.25	32.2±1.19
HI1563	24.3±1.07	26.2±1.05	30.6±1.06	29.6±1.05	31.0±1.06	31.8±0.93
HI1571	25.9±1.16	26.5±1.12	30.3±1.14	29.9±1.18	31.3±1.15	31.1±1.09
HI8703	25.5±1.65	24.6±1.50	31.1±1.57	30.8±1.59	22.3±1.59	31.7±1.73
HI8704	25.0±1.63	23.5±1.57	30.8±1.60	29.4±1.55	29.9±1.57	34.3±1.70
HUW234	24.1±1.34	29.8±1.33	30.5±1.34	28.9±1.37	30.2±1.33	21.7±1.36
LOK62	24.0±1.09	23.6±1.06	31.1±1.07	28.4±1.08	31.6±1.08	31.8±0.97
MP3304	24.8±1.47	25.0±1.36	30.5±1.42	30.0±1.37	31.0±1.36	31.4±1.40
MP4010	34.4±1.37	23.2±1.37	29.8±1.37	29.2±1.27	29.9±1.32	33.3±1.31
NIAW34	26.0±1.51	22.4±1.33	31.2±1.42	28.9±1.36	31.1±1.24	32.4±1.27
NW2036	24.7±1.44	23.1±1.44	30.1±1.44	29.1±1.46	31.3±1.43	31.8±1.51
PBW373	25.1±1.25	22.9±1.23	32.3±1.11	29.8±1.17	31.5±1.06	30.4±0.99
PBW590	26.1±1.28	23.1±1.19	30.4±1.13	28.6±1.14	30.2±1.08	32.3±1.00
PBW639	27.1±1.22	22.4±1.25	30.2±1.10	30.7±1.09	23.2±1.04	32.1±0.94
PDW322	27.2±1.35	23.3±1.43	31.3±1.16	27.0±1.06	32.7±1.05	30.5±0.93
RAJ4083	24.2±1.71	23.0±1.61	28.8±1.34	30.3±1.29	29.0±1.15	30.5±1.15
UAS320	24.3±1.58	23.5±1.58	30.1±1.28	29.1±1.23	31.9±1.10	31.2±1.07
UAS428	24.7±1.46	23.4±1.37	30.8±1.22	28.4±1.36	32.1±1.09	31.4±1.12
WH1021	25.2±1.08	23.1±1.05	30.7±1.03	30.0±1.04	32.2±1.00	31.3±0.87
WHD946	26.0±1.24	22.5±1.23	29.5±1.11	30.1±1.08	31.4±1.04	32.2±0.93
Range	21.7-34.4	22.4-29.8	28.8-32.3	27.0-30.8	22.3-34.1	21.7-34.3
Mean	25.12	23.96	30.34	29.47	30.72	31.33
CD at 5%	Replications TS= 1.12 Treatments TS= NS			Replications LS=1.13 Treatments LS=NS		

Values are mean±SD of three replicates

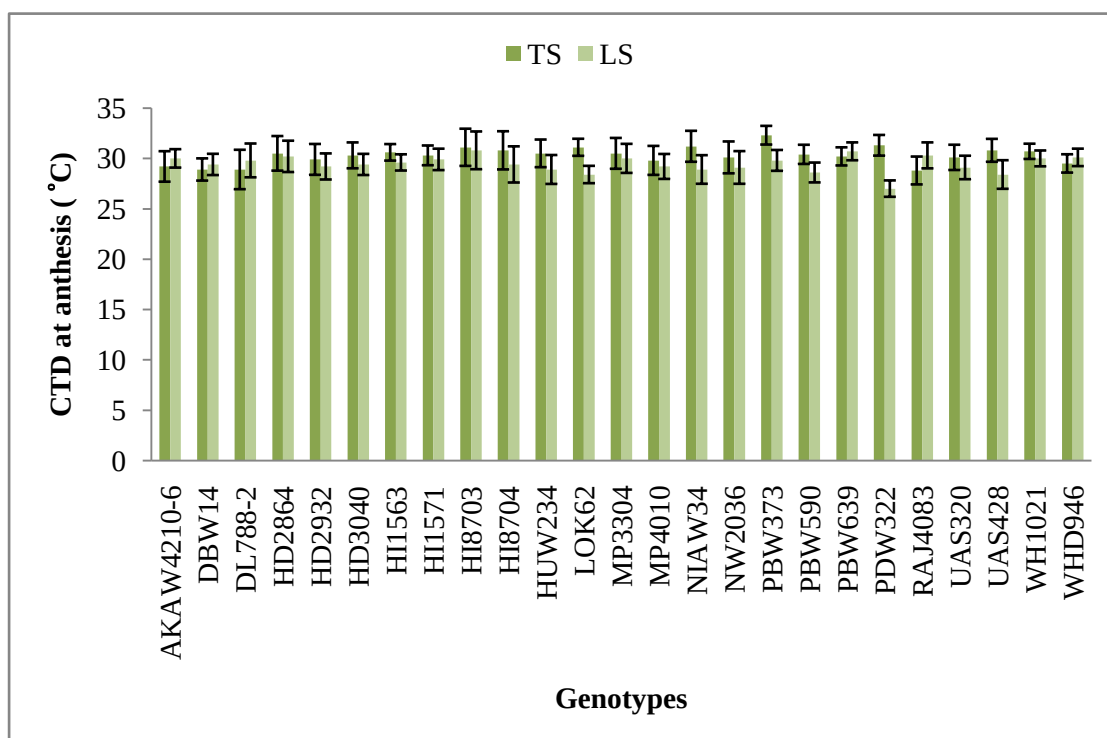


Fig 2e: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

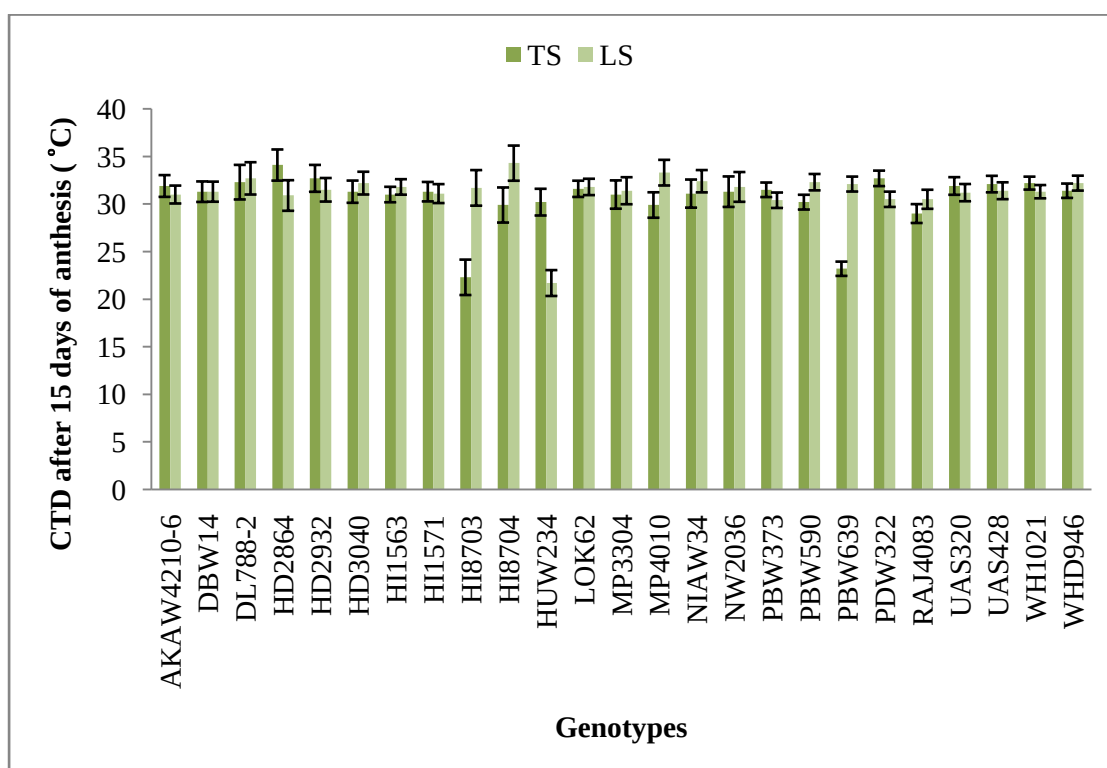


Fig 2f: Canopy temperature depression (CTD) recorded at different growth stages in wheat genotypes under timely and late sown conditions in MLHT II

Canopy temperature depression (Fig 2a-2f) was decreased under late sown conditions. Results were in accordance with Bahar *et al* (2008) who observed that CTD was found to be decreased under late sown conditions. CTD is a direct function of evapotranspiration rate, which is determined by various physiological processes such as stomatal conductance, photosynthetic rate, vascular capacity etc.

4.1.3 Days to Heading

In MLHT-I, Days to heading (Table 3a) ranged from 98 to 110 days under timely sown and 83 to 98 days under late sown conditions with mean values of 102 and 90 days for timely and late sown conditions, respectively. The genotypes HD 3095, HD 3096 and HD 2932 had taken more days to form head under timely sown conditions and genotypes GW 431, HD 3091, PBW 670 and HD 2932 had taken more days for heads to form under late sown conditions. Genotype GW 431 was found to be tolerant.

In MLHT-II, days to heading (Table 3b) ranged from 106 to 126 days under timely sown and 86 to 98 days under late sown conditions with mean values of 114 and 90 days for timely and late sown conditions, respectively. The genotypes HUW 234, LOK 62, PBW 590, RAJ 4083 and WHD 946 had taken highest 126 days for heads to occur under timely sown conditions. The varieties DL 788-2, MP 4010, NW 2036, PBW 590 and RAJ 4083 had taken higher days for heads to occur under late sown conditions. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

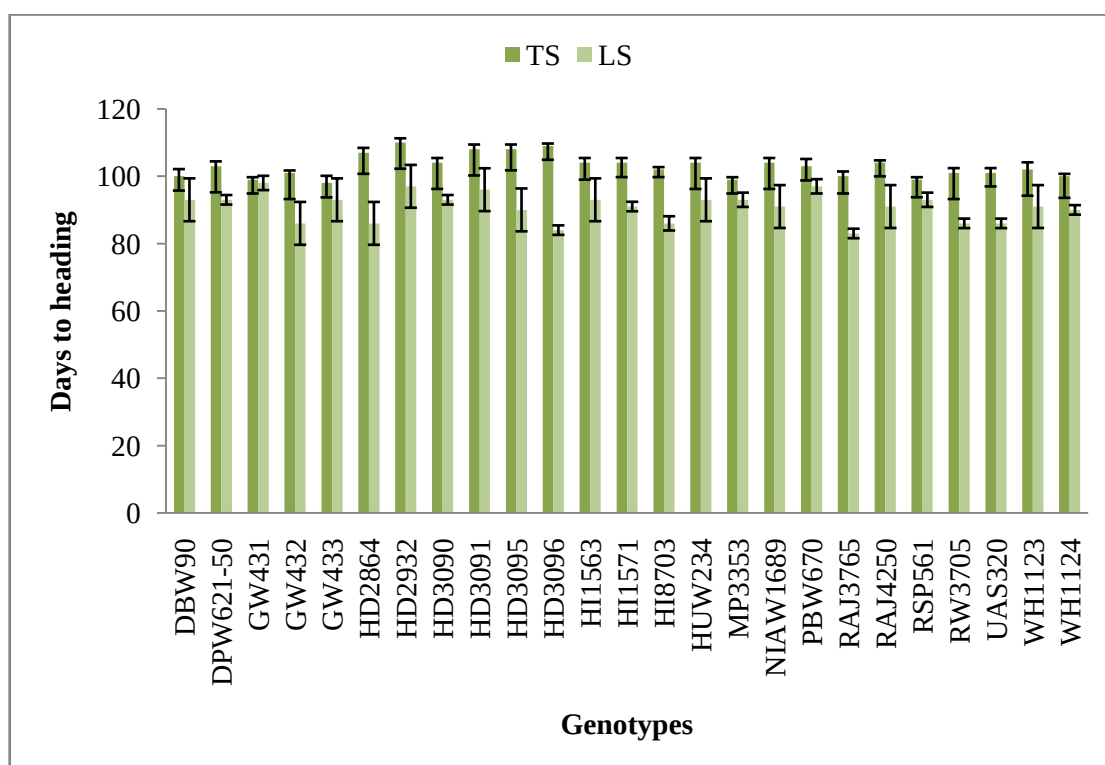


Fig 3a: Days to heading recorded in wheat genotypes under timely and late sown conditions in MLHT I

Table 3a: Days to heading, peduncle length and plant height recorded in wheat genotypes under timely and late sown conditions in MLHT I

Genotype	Days to heading		Peduncle length (cm)		Plant height (cm)	
	TS	LS	TS	LS	TS	LS
DBW90	100±2.12	93±2.12	12.6±0.42	12.3±0.21	99±6.36	89±0.71
DPW621-50	103±1.41	93±2.12	12.1±0.07	5.8±4.38	90±1.20	75±10.61
GW431	99±0.71	98±1.41	9.2±1.98	7.9±2.90	88±1.41	79±7.78
GW432	101±0.71	86±2.83	13.7±1.20	11.7±0.21	92±1.41	80±7.07
GW433	98±2.12	93±1.41	19±4.95	13.7±1.20	91±0.71	83±4.95
HD2864	107±1.41	86±.71	16.8±3.39	10.7±0.92	88±1.41	84±4.24
HD2932	110±5.66	97±1.41	16.7±3.32	11.8±0.14	75±10.61	70±14.14
HD3090	104±1.41	93±1.41	17.9±4.17	14.8±1.98	75±10.61	70±14.14
HD3091	108±1.41	96±2.83	13.3±0.92	14.2±1.56	96±4.27	80±7.07
HD3095	108±1.41	90±1.41	13.7±1.20	10.2±1.27	79±7.78	75±10.61
HD3096	109±0.71	84±1.41	18.8±4.81	12.8±0.57	86±2.83	95±3.54
HI1563	104±1.41	93±0.71	16.7±3.32	12.8±0.57	85±3.54	79±7.78
HI1571	104±1.41	91±0.71	18.3±4.45	12.1±0.07	88±1.41	82±5.56
HI8703	102±0.71	86±1.41	13.4±0.99	12.2±0.14	94±2.83	86±2.83
HUW234	104±1.41	93±2.12	20.4±5.94	12.4±0.28	82±5.66	82±5.66
MP3353	99±0.71	93±2.12	19±4.95	11.4±0.42	93±2.12	81±6.36
NIAW1689	104±1.41	91±0.71	12.7±0.49	12.3±0.21	85±3.54	75±10.61
PBW670	103±2.12	97±1.41	16±2.83	16.3±3.04	88±1.41	80±7.07
RAJ3765	100±1.41	83±2.12	15±2.12	12±0.01	80±7.07	80±7.07
RAJ4250	104±0.71	91±0.71	16.5±3.18	13.2±0.85	88±1.41	80±7.07
RSP561	99±0.71	93±2.12	18.4±4.53	11.9±0.07	98±5.66	75±10.61
RW3705	101±1.41	86±1.41	20.8±6.22	22.4±7.35	100±7.07	90±0.00
UAS320	101±1.41	86±1.41	17.3±3.75	15.3±2.33	96±4.24	93±2.12
WH1123	102±2.12	91±1.41	16±2.83	12.1±0.07	97±4.95	86±2.83
WH1124	100±0.71	90±3.54	19±4.95	18.5±4.60	93±2.12	85±3.54
Range	98-110	83-98	9.2-20.8	5.8-22.4	75-100	70-95
Mean	102	90	16.1	12.8	89	81
CD at 5% Replications Treatments	TS= 0.89	LS=0.54	TS=3 .08	LS=1.01	TS= 0.67	LS=4.45
	TS=3.15	LS=1.91	TS= 3.09	LS=1.06	TS= 2.38	LS=4.57

Values are mean±SD of five replicates

Table 3b: Days to heading, peduncle length and plant height recorded in wheat genotypes under timely and late sown conditions in MLHT II

Genotype	Days to heading		Peduncle length (cm)		Plant height (cm)	
	TS	LS	TS	LS	TS	LS
AKAW4210-6	114±13.44	86±6.36	12.3±1.63	7.4±1.84	87±3.82	75±5.09
DBW14	106±7.78	93±1.41	15.5±3.89	10.4±0.28	90±5.66	82±0.28
DL788-2	114±13.44	98±2.12	9.4±0.42	5.7±3.04	88±3.96	66±11.03
HD2864	106±7.78	86±6.36	14.3±3.04	10.0±0.00	83±0.99	62±14.00
HD2932	114±13.44	86±6.36	16.2±4.38	10.3±0.21	80±1.41	79±1.84
HD3040	114±13.44	86±6.36	17.5±5.30	13.3±2.33	78±2.83	72±6.79
HI1563	106±7.78	86±6.36	16.1±4.31	10.5±0.35	88±3.96	77±3.39
HI1571	106±7.78	93±1.41	17.2±5.09	11.4±0.99	88±4.53	85±2.26
HI8703	106±7.78	86±6.36	15.3±3.75	12.0±1.41	75±4.81	96±9.76
HI8704	114±13.44	86±6.36	15.9±4.17	14.7±3.32	87±3.54	77±3.25
HUW234	126±21.92	93±1.41	15.1±3.61	13.9±2.76	85±1.98	89±4.67
LOK62	126±21.92	86±6.36	11.7±1.20	13.8±2.69	77±3.25	77±3.39
MP3304	121±18.38	93±1.41	13.0±2.12	14.2±2.97	78±2.55	82±0.28
MP4010	121±18.38	98±2.12	16.2±4.38	14.5±3.18	77±3.25	76±4.38
NIAW34	106±7.78	86±6.36	19.4±6.65	7.0±3.12	90±5.80	91±6.36
NW2036	126±21.92	98±2.12	16.9±4.88	10.5±0.35	74±5.80	75±4.95
PBW373	106±7.78	86±6.36	16.9±4.88	8.5±1.06	87±3.82	93±7.78
PBW590	126±21.92	98±2.12	11.7±1.20	8.5±1.06	78±3.11	84±1.41
PBW639	114±13.44	93±1.41	14.6±3.25	10.1±0.07	98±11.45	91±6.65
PDW322	114±13.44	86±6.36	12.9±2.05	10.5±0.35	82±0.14	74±5.37
RAJ4083	126±21.92	98±2.12	13.8±2.69	11.7±1.20	76±4.38	88±4.10
UAS320	106±7.78	93±1.41	16.2±4.38	13.2±2.26	94±8.77	78±2.55
UAS428	114±13.44	93±1.41	16.9±4.88	16.5±4.60	81±0.71	81±0.71
WH1021	106±7.78	86±6.36	18.1±5.73	16.5±4.60	94±8.34	86±2.55
WHD946	126±21.92	93±1.41	17.6±5.37	10.6±0.42	91±6.51	84±1.27
Range	106-126	86-98	9.4-19.4	5.7-16.5	74-98	62-96
Mean	114	90	15	11	84	78
CD at 5% Replications Treatments	TS= 4.33 LS=0.75 TS=4.52 LS=2.64		TS=1.89 LS=0.54 TS=1.95 LS=1.07		TS=0.31 LS=0.34 TS= 1.13 LS=1.23	

Values are mean±SD of five replicates

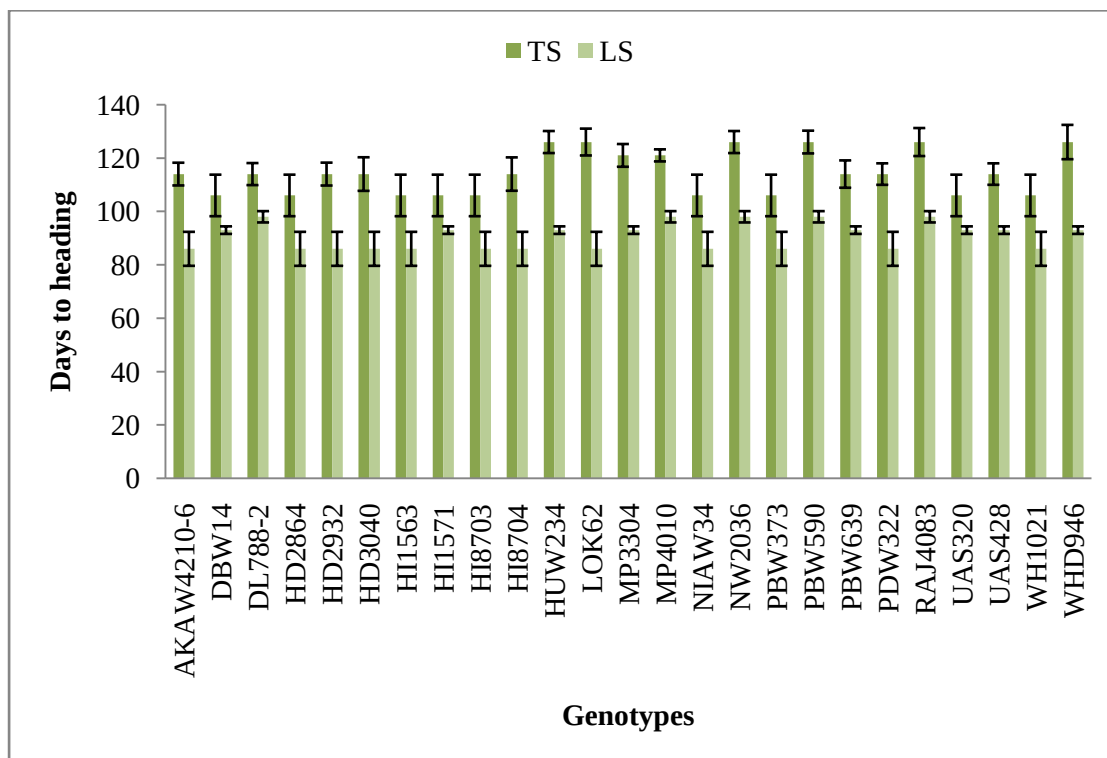


Fig 3b: Days to heading recorded in wheat genotypes under timely and late sown conditions in MLHT II

4.1.4 Peduncle Length

In MLHT-I, peduncle length (Table 3a) ranged from 9.2 to 20.8 cm under timely sown and 5.8 to 22.4 cm under late sown conditions with mean values of 16.1 and 12.8 cm for timely and late sown conditions respectively.

The genotypes HI 1157, HD 3096, HUW 234, MP 3353, RW 3705 and WH 1124 had higher peduncle length under timely sown conditions and genotypes RW 3705 and WH 1124 had higher peduncle length under late sown conditions. Genotype RW 3705 was found to be tolerant and genotypes PBW 670 and WH 1124 had no change in peduncle length and genotypes DBW 90 and NIAW 1689 were found to be susceptible under heat stress.

In MLHT-II, peduncle length (Table 3b) ranged from 9.4 to 19.4 cm under timely sown and 5.7 to 16.5 cm under late sown conditions with mean values of 15.2 and 11.4 cm for timely and late sown conditions respectively. Genotypes HD 3040, HI 1157, NIAW 34, NH 1021 and WHD 946 has higher peduncle length under timely sown conditions and genotypes HI 8704, MP 3304, MP 4010, UAS 428 and WH 1020 had higher peduncle length under late sown conditions.

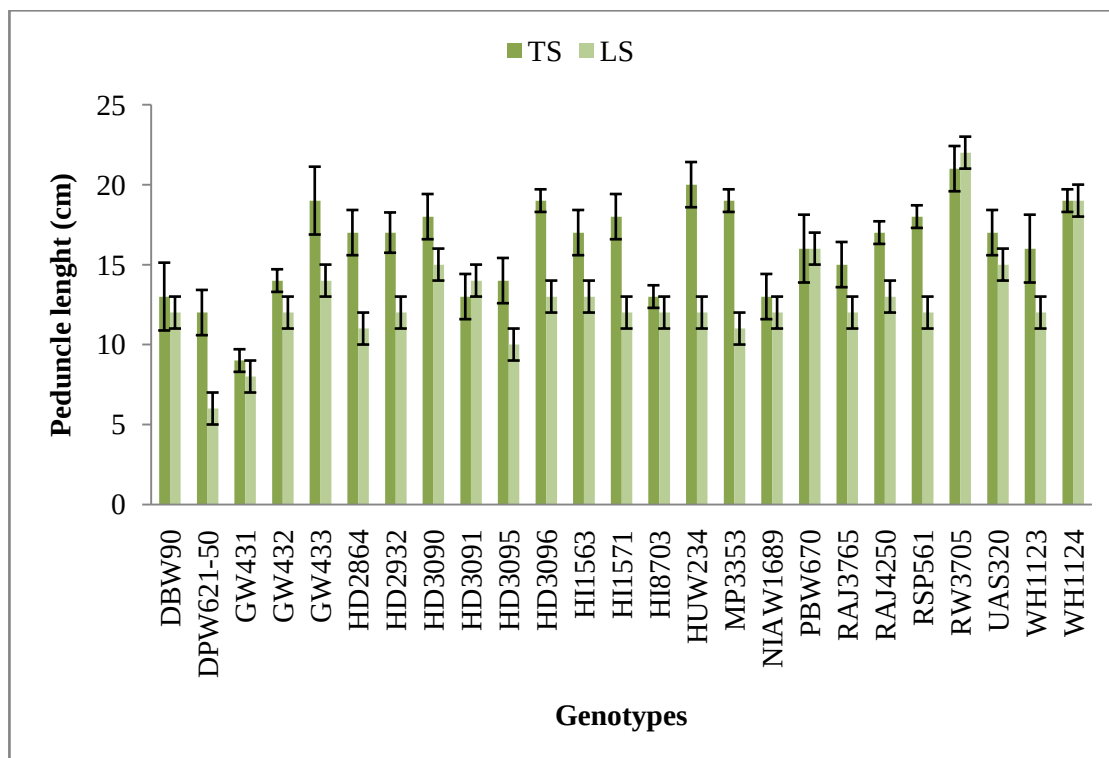


Fig 4a: Peduncle length recorded in wheat genotypes under timely and late sown conditions in MLHT I

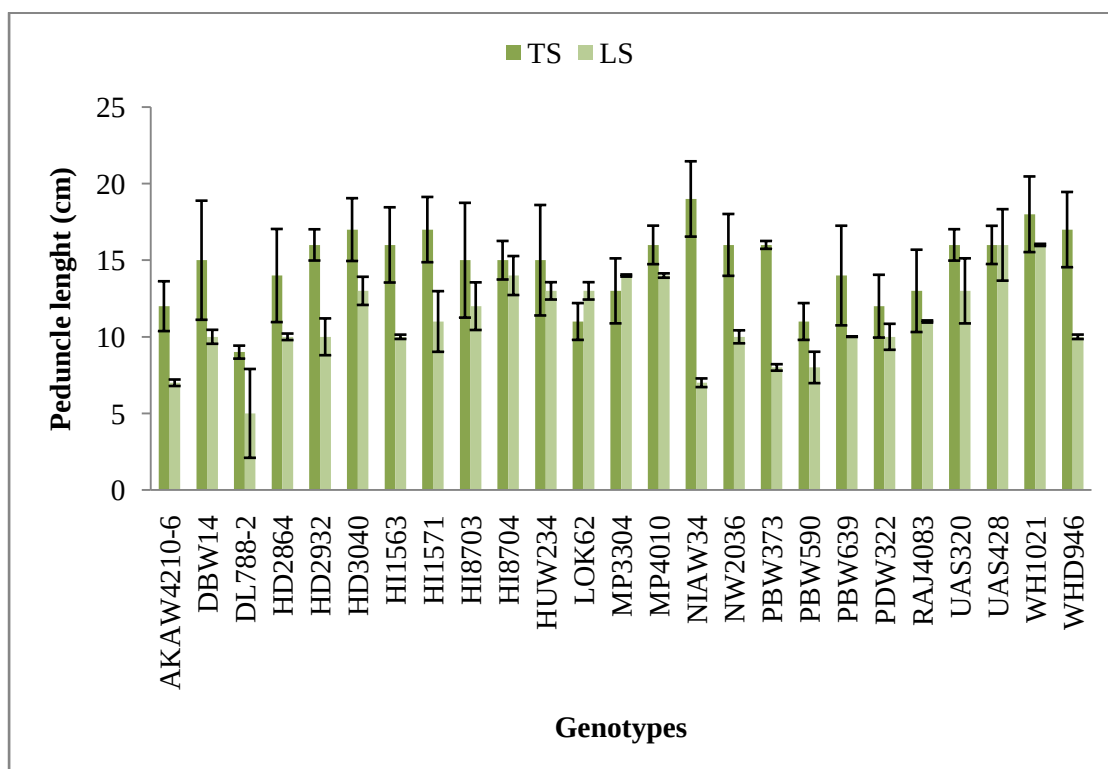


Fig 4b: Peduncle length recorded in wheat genotypes under timely and late sown conditions in MLHT II

Genotype MP 3304 was found to be tolerant under heat stress. Genotype UAS 428 had no change in peduncle length. Genotypes HI8704 and WH 1021 were found to be susceptible under heat stress. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

4.1.5 Plant Height

In MLHI-I, plant height (Table 3a) ranged from 75 to 100 cm under timely sown and 70 to 95 cm under late sown conditions with mean values of 89 and 81 cm for timely and late sown conditions respectively. The genotypes DBW 90, RSP 561, RW 3705 and WH 1123 had higher plant height under timely sown conditions. The genotypes HD 3096, RW 3705 and UAS 320 had higher plant height under late sown conditions. Genotypes HUW 234 and RAJ 3765 had no change in plant height and all other entries showed decreased plant height under late sown conditions.

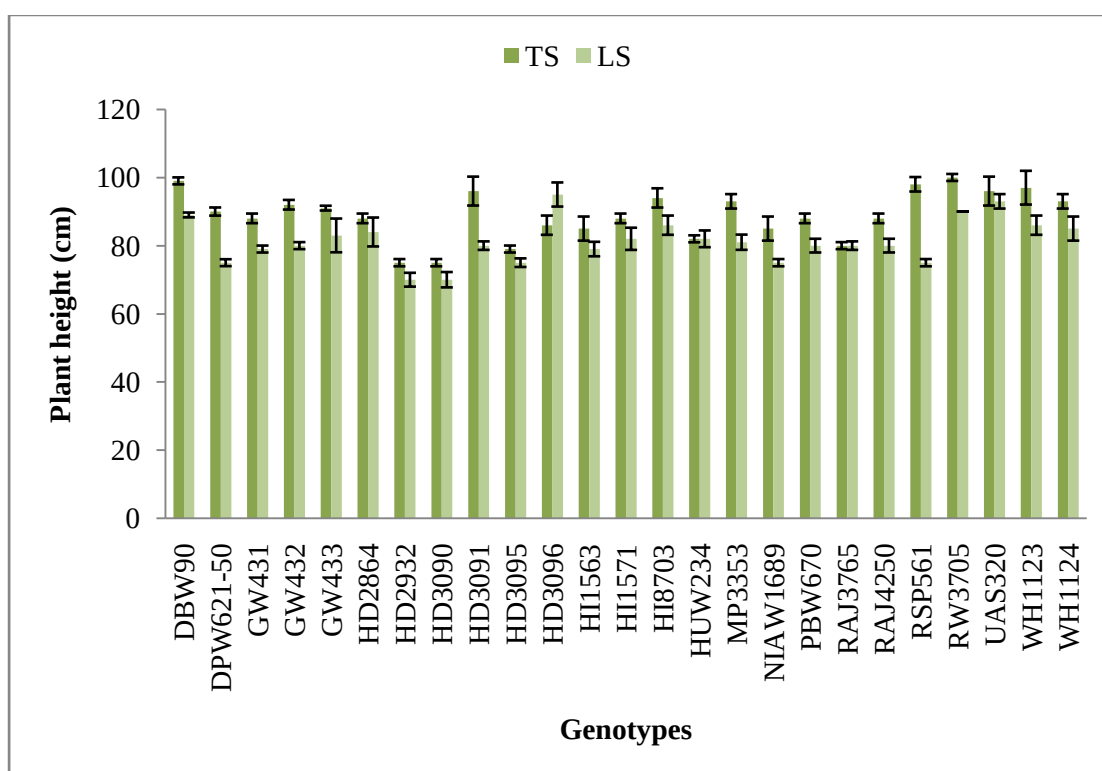


Fig 5a: Plant height recorded in wheat genotypes under timely and late sown conditions in MLHT I

In MLHT-II, plant height (Table 3b) ranged from 74 to 98 cm under timely sown and 62 to 96 cm under late sown conditions with mean values of 84 and 78 cm for timely and late sown conditions, respectively. Genotypes PBW 639, UAS 320, WH 1021 and WHD 946 had higher plant height under timely sown conditions and genotypes HI 8703, NIAW 34, PBW 373 and PBW 639 had higher plant height under late sown conditions. The plant height of timely sown conditions was more than the late sown conditions.

Genotypes NIAW 234 and NW 2036 were found to be tolerant under heat stress. Genotypes LOK 62 and UAS 428 had no change in plant height. Genotypes HD 2932 and MP 4010 were found to be tolerant under heat stress. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

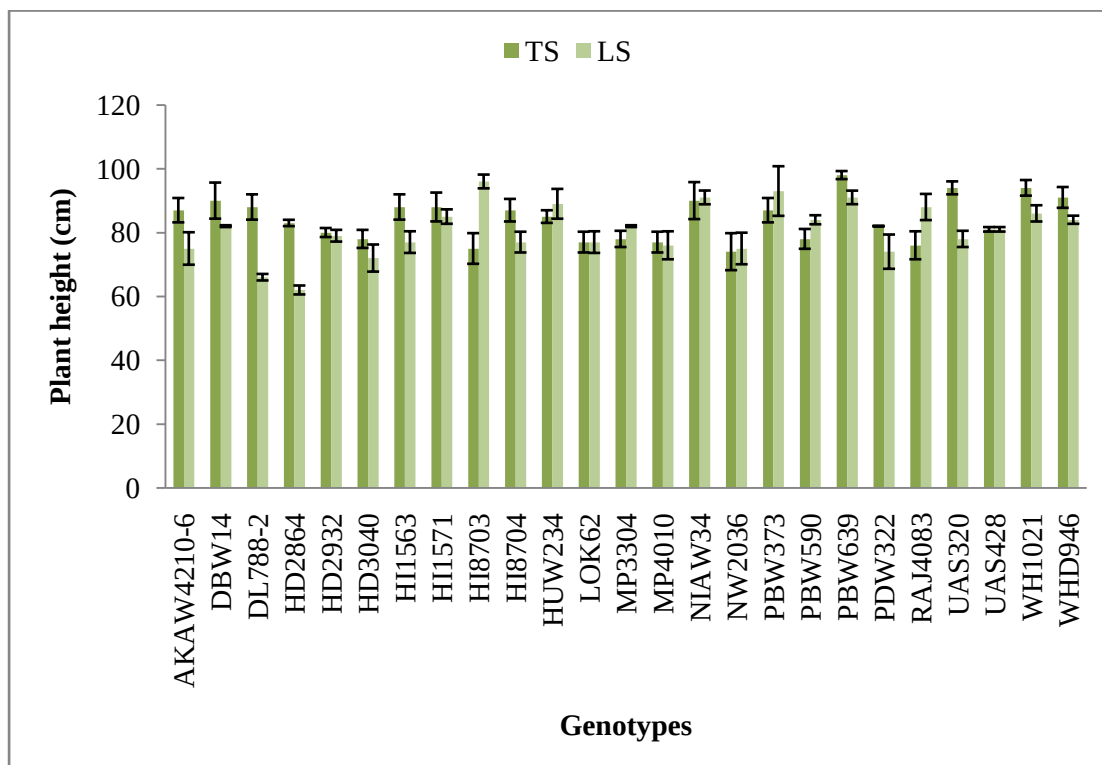


Fig 5b: Plant height recorded in wheat genotypes under timely and late sown conditions in MLHT II

Days to heading (Fig 3a, b), peduncle length (Fig 4a, b) and plant height (Fig 5a, b) was reduced significantly in late sown conditions under heat stress. Radmehr *et al* (1996) reported that increase in temperature results in decreased plant height. Slafer and Rawson (1995) reported that increase in temperature always reduce the time to heading. Wardlaw *et al* (1980) also reported reduction in time to heading, peduncle length, grain filling period and plant height was reduced in late sown conditions. Days to heading, peduncle length and plant height was reduced under late sown condition in both the trials MLHT-I and MLHT-II.

4.1.6 Grain number per spike in MLHT-I

In MLHT I, Grain no. per spike (Table 4a) ranged from 32 to 61 under timely sown conditions and 35 to 58 under late sown conditions with mean values of 49 and 48 under timely and late sown conditions respectively. The genotypes DPW 621-50, HD 2864 and WH 1123 had more number of grain per spike under timely sown conditions and genotypes GW 431, HD 3046 and MP 3353 had more number of grains under late sown conditions. Genotypes GW 431, GW 433, HI 1563, MP 3353, RW 3705 and WH 1124 were found to be

tolerant and genotypes HI 8703, PBW 670, HUW 234, WH 1123, HD 2932 and RAJ 4250 were found to be susceptible under heat stress.

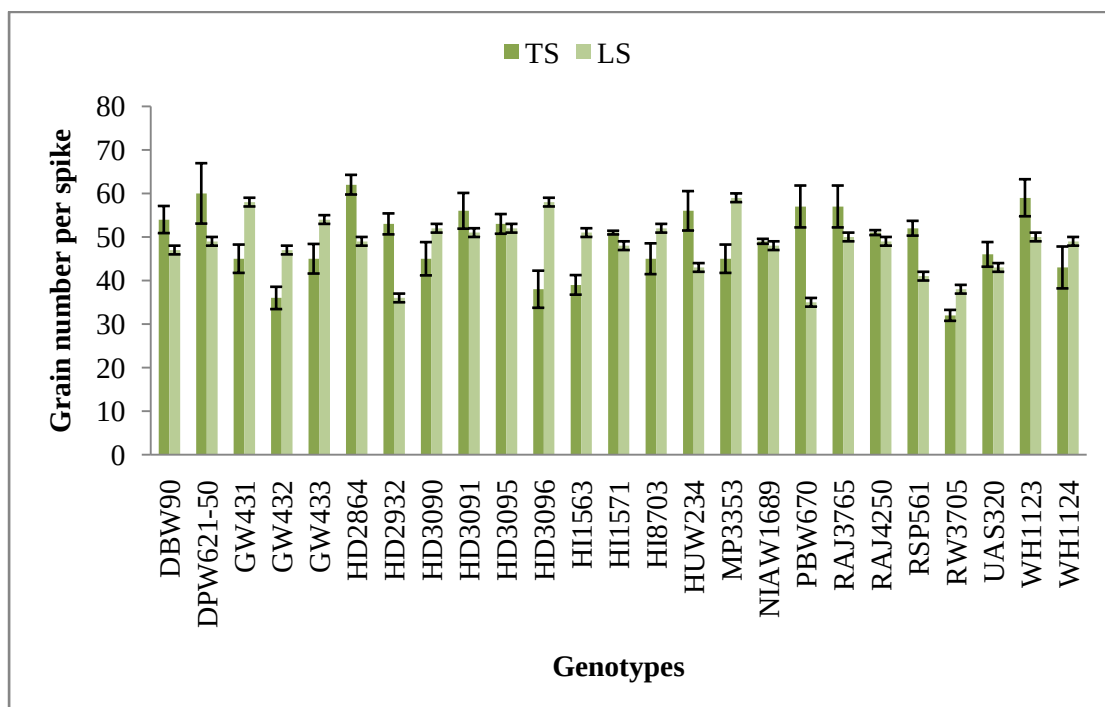


Fig 6a: Grain number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

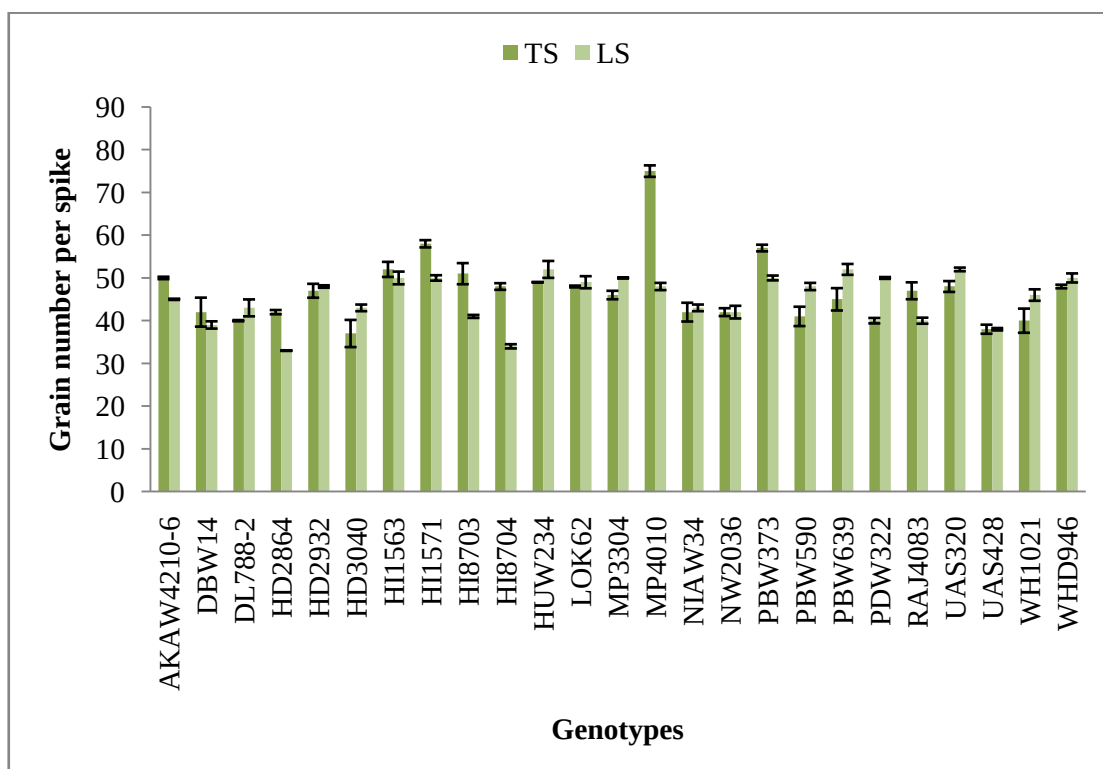


Fig 6b: Grain number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

In MLHT-II, grain number per spike (Table 4b) ranged from 37 to 75 under timely sown and 32 to 58 under late sown conditions with mean values of 47 and 45, respectively. Genotypes HI 1571, MP 4010 and PBW 373 were having more number of grains per spike under timely sown conditions and genotypes HUW 234, PBW 639 and UAS 320 had more number of grains per spike under late sown conditions.

Genotypes DL 788-2, HD 2932, HD 3040 and NIAW 234 were found to be tolerant. Genotypes NW 2036 and UAS 428 had no change in number of grains per spike.

4.1.7 Grain weight per spike

In MLHT-I, grain wt. per spike (Table 4a) ranged from 6.4 to 13.0 gm under timely and 6.1 to 11.0 gm under late sown conditions respectively with mean values of 9.8 and 8.8 gm. Genotypes DPW 621-50, HD 2864, HD 3091, PBW 670, RAJ 3765 and WH 1136 had higher grain weight per spike under timely sown conditions. Genotypes GW 431, HD 3096, HI 1563 and MP 3353 had higher grain weight per spike under late sown conditions.

Genotypes GW 431, GW 432, HD 3096, HI 1563, MP3353, RW 3705 and WH 1124 showed increased grain weight per spike under late sown conditions and hence were found to be tolerant under heat stress. The mean value of grain weight per spike under late sown conditions was decreased due to heat stress.

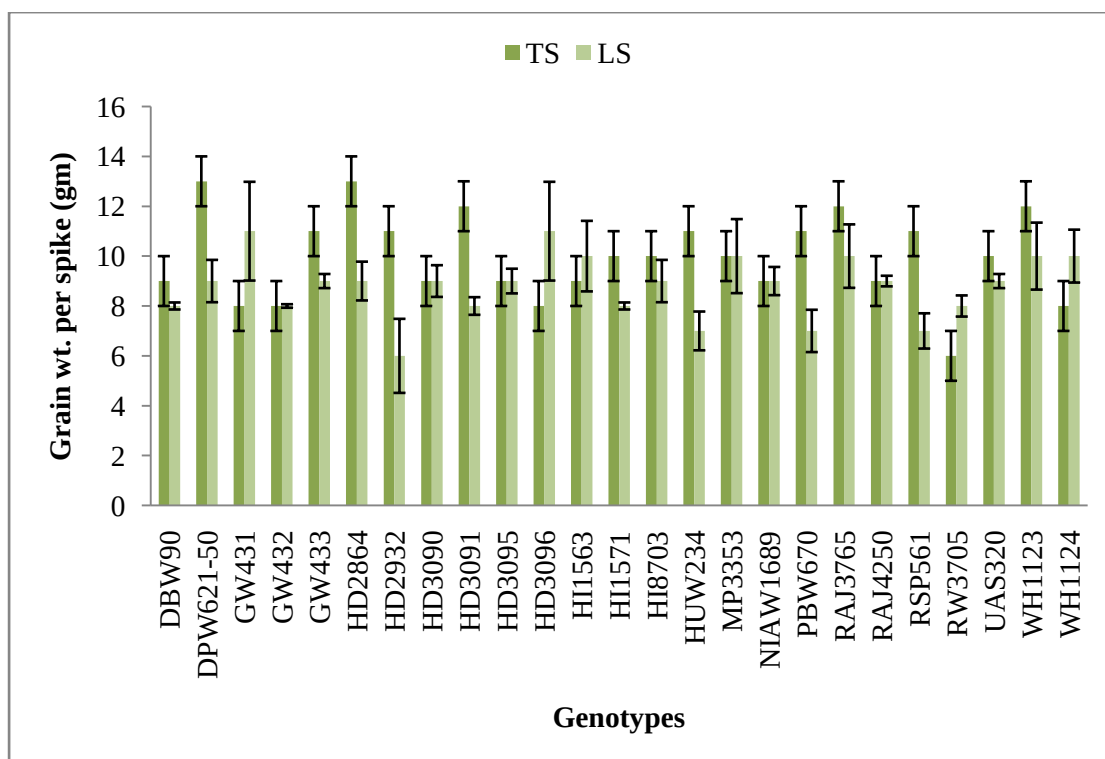


Fig 7a: Grain weight per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

In MLHT-II, grain wt. per spike (Table 4b) ranged from 3.9 to 9.7 gm under timely sown conditions and 5.4 to 10.6 gm under late sown condition with mean values of 6.8 and 7.9 gm under timely and late sown conditions. Genotypes HI 8703, HI 8704, MP 3304, NW 2036 and PBW 373 had higher grain weight under timely sown conditions and genotypes HUW 234, MP 3304, NIAW 34, PDW 322, UAS 320 and WH 1021 had higher grain weight per spike under late sown conditions.

Genotypes AKAW 4210-6, DL 788-8, HD 3040, HUW 234, MP 4010, UAS 320 had increased grain weight per spike under late sown conditions and found to be tolerant under heat stress. HI 8703, HI 8704 and PBW 373 showed decreased grain weight per spike under late sown conditions. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

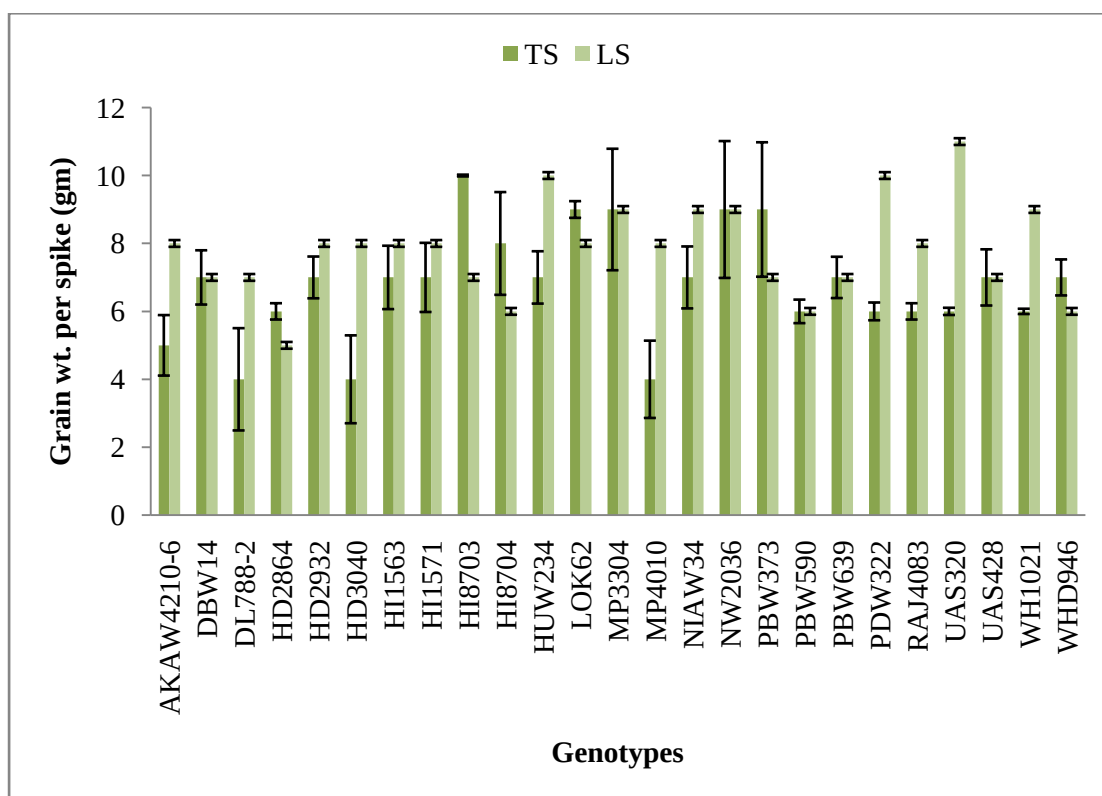


Fig 7b: Grain weight per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

4.1.8 Spike number per spike

In MLHT-I, spike number per spike (Table 4a) ranged from 15.4 to 21.0 under timely sown and 16.2 to 21.0 under late sown conditions with mean values of 18.0 and 18.4 for timely and late sown conditions respectively.

Genotypes HD 2864, HI 1571, HD 3095, HI 1563, MP 3353 and WH 1123 had

higher spike number per spike under timely sown conditions and genotypes HD 3090, HI 1563, RAJ 3765, RSP 561, HD 2939 and WH 1124 had higher spike number under late sown conditions.

Genotypes DBW 90, GW 431, HD 3090, HI 8703 and WH 1124 were found to be tolerant heat stress. Genotypes GW 433, HI 1563, HUW 234 and PBW 670 had no change in spike number per spike.

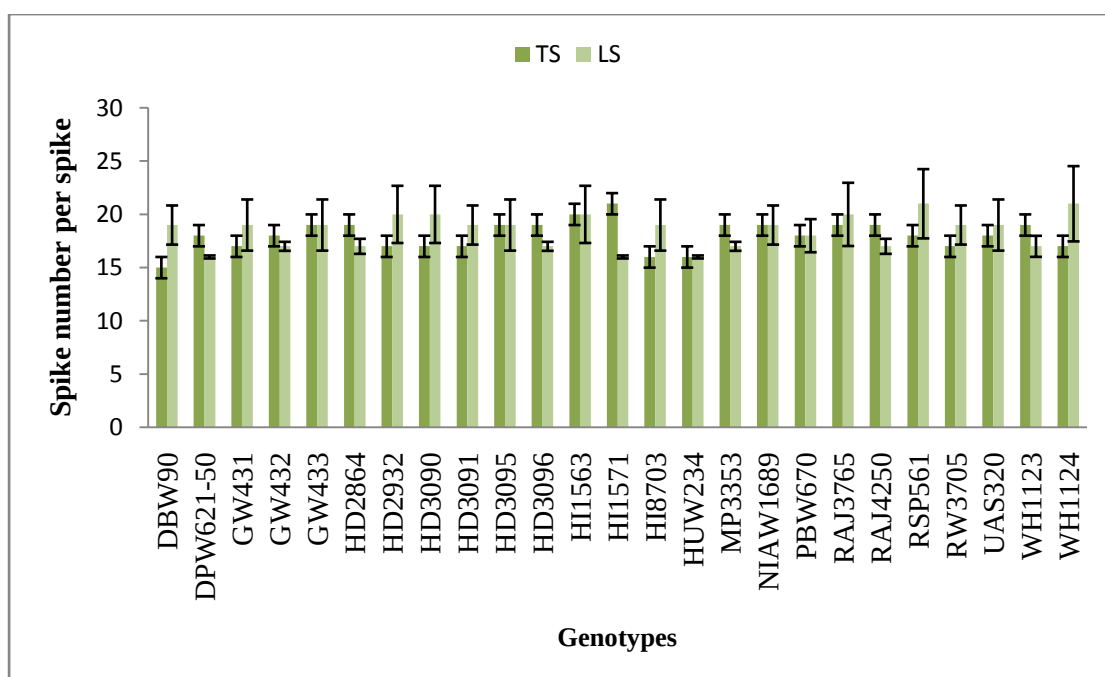


Fig 8a: Spike number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

In MLHT-II, spike number per spike (Table 4b) ranged from 15.0 to 21.8 under timely sown conditions and 15.0 to 21.4 under late sown conditions with mean value of 18.4 and 18.2 for timely and late sown conditions respectively.

Genotypes HI 1563, HI 8703, NW 2036, PBW 639, UAS 320 and WHD 946 had higher spike number under timely sown conditions and genotypes AKAW 4210-6 and MP 4010, PBW 639 and WHD 946 had higher spike number under late sown condition.

Genotypes DL 788-2, UAS 428 and HI 1571 were found to be tolerant under heat stress. Genotypes HI 8704 and PBW 590 had no change in spike number per spike. It is found to be significant ($p < 0.05$) under late sown conditions in both the trials MLHT I and MLHT II.

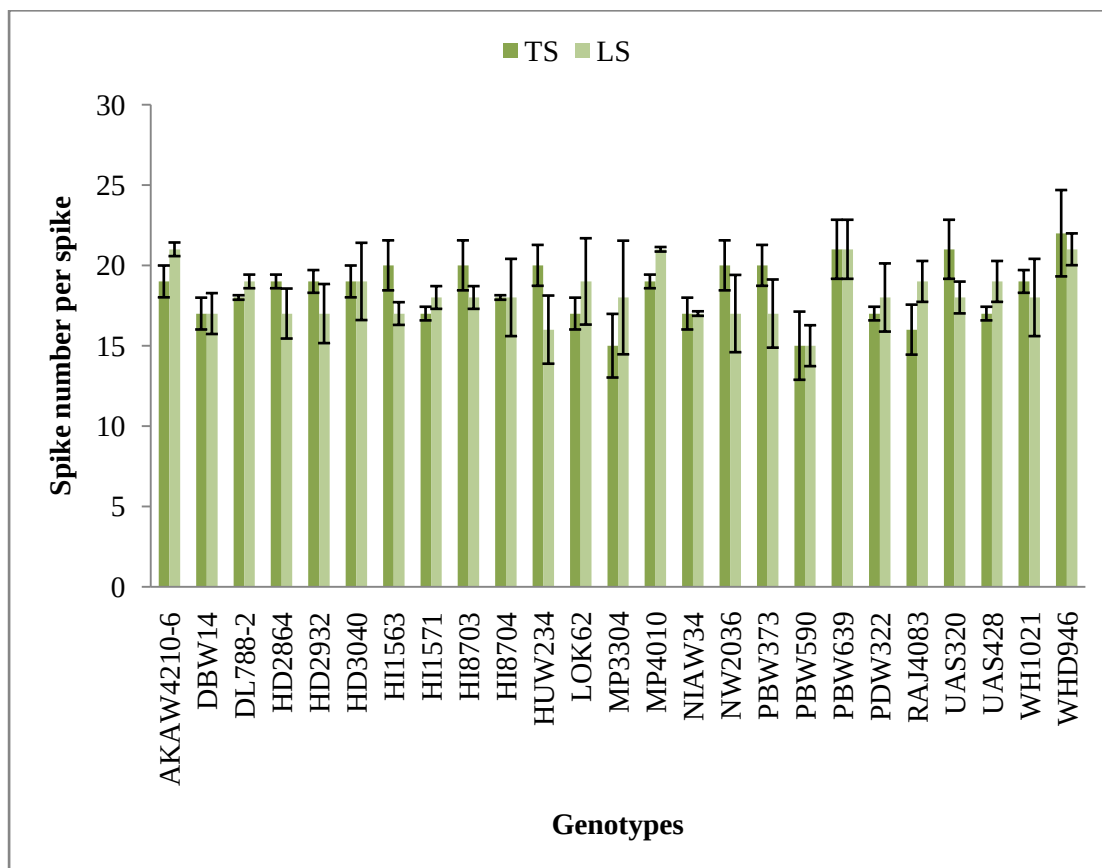


Fig 8b: Spike number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

Grain number per spike (Fig 6a, b), grain wt. per spike (Fig 7a, b) and spike number per spike (Fig 8a, b) were decreased in most of the genotypes in heat stress conditions. Johnson and Kanemasu (1983) also supported similar findings.

4.1.9 Total Biomass

In MLHT-I, the total biomass (Table 5a) ranged from 4.8 to 8.4 kg under timely sown conditions and 4.8 to 6.8 kg under late sown conditions with mean values of 6.5 and 5.8 kg for timely and late sown conditions, respectively. The genotypes GW 431, GW 432, HD 3090, HI 1571, HI 1563, UAS 320 and WH 1124 had higher total biomass under timely sown conditions. Genotypes HD 2864, HI 1571, HD 3096, HI 1563, NIAW 1689, RW 3705, UAS 320 and WH 1123 had higher total biomass under late sown conditions. Genotypes HD 2864, HD 2932, HD 3096 and NIAW 1689 were found to be tolerant under heat stress. Genotypes HD 3095 and RAJ 4250 had no change in total biomass.

Table 4a: Grain number per spike, grain weight per spike and spike number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

Genotype	Grain no. per spike		Grain wt. per spike (gm)		Spike no. per spike	
	TS	LS	TS	LS	TS	LS
DBW90	54±3.11	47±1.98	8.6±0.28	8±0.14	15.4±0.42	18.6±1.84
DPW621-50	60±6.93	49±0.42	13±3.39	9.4±0.85	17.8±1.27	16.2±0.14
GW431	45±3.25	58±5.66	8±0.14	11±1.98	16.6±0.42	19.4±2.40
GW432	36±2.56	47±1.84	7.5±0.49	8.1±0.07	18.2±1.56	16.6±0.42
GW433	45±3.39	54±2.83	10.5±1.63	8.6±0.28	18.6±1.84	19.4±2.40
HD2864	62±2.26	49±0.85	12.7±3.18	9.3±0.78	19.4±2.40	17±0.71
HD2932	53±2.40	36±1.02	10.7±1.77	6.1±1.48	17±0.71	19.8±2.69
HD3090	45±3.82	52±1.27	9.4±0.85	9.1±0.64	17±0.71	19.8±2.69
HD3091	56±4.10	51±0.99	11.7±2.47	7.7±0.35	17±0.71	18.6±1.84
HD3095	53±2.26	52±1.70	9.3±0.78	8.9±0.49	19.4±2.40	19.4±2.40
HD3096	38±4.26	58±5.66	8.1±0.07	11±1.98	19±2.12	16.6±0.42
HI1563	39±2.25	51±0.71	8.5±0.21	10.2±1.41	19.8±2.69	19.8±2.69
HI1571	51±0.42	48±1.41	9.6±0.99	8.4±0.14	21±3.54	16.2±0.14
HI8703	45±3.54	52±1.70	10.1±1.34	9.4±0.85	16.2±0.14	19.4±2.40
HUW234	56±4.53	43±4.95	11.3±2.19	7.1±0.78	15.8±0.14	16.2±0.14
MP3353	45±3.25	59±6.08	9.5±0.92	10.3±1.48	19.4±2.40	16.6±0.42
NIAW1689	49±0.57	48±1.70	9.3±0.78	9±0.57	19±2.12	18.6±1.84
PBW670	57±4.81	35±10.47	11.4±2.26	7±0.85	17.8±1.27	18.2±1.56
RAJ3765	57±4.81	50±0.00	11.9±2.62	10±1.27	18.6±1.84	20.2±2.97
RAJ4250	51±0.57	49±0.99	9.1±0.64	8.5±0.21	19±2.12	17±0.71
RSP561	52±1.70	41±6.22	11±1.98	7.2±0.71	17.8±1.27	20.6±3.25
RW3705	32±1.26	38±8.34	6.4±1.27	7.6±0.42	17.4±0.99	18.6±1.84
UAS320	46±2.83	43±4.95	9.7±1.06	8.6±0.28	17.8±1.27	19.4±2.40
WH1123	59±4.25	50±0.28	12.2±2.83	10.1±1.34	19.4±2.40	17.4±0.99
WH1124	43±4.81	49±0.99	7.6±0.42	9.7±1.06	17.4±0.99	21±3.54
Range	32-62	35-58	6.4-13.0	6.1-11.0	15.4-21.0	16.2-21.0
Mean	49	48	9.8	8.8	18.0	18.4
CD at 5% Replications Treatments	TS= 1.29 LS=13.57		TS=0.024 LS=0.55		TS=NS LS=0.86	

Values are mean±SD of five replicates

Table 4b: Grain number per spike, grain weight per spike and spike number per spike recorded after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

Genotype	Grain no. per spike		Grain wt. per spike (gm)		Spike no. per spike	
	TS	LS	TS	LS	TS	LS
AKAW4210-6	50±0.99	45±2.69	4.7±0.89	7.8±1.27	19.4±0.99	20.6±1.84
DBW14	42±4.95	39±7.35	7.1±0.80	7.2±0.86	16.6±0.99	17±0.71
DL788-2	40±28.99	43±3.96	3.9±1.51	7.1±0.78	17.8±0.14	19±0.71
HD2864	42±4.95	33±11.46	5.7±0.24	5.4±0.40	18.6±0.42	17±0.71
HD2932	47±1.13	48±0.57	6.9±0.62	7.5±1.06	19±0.71	17±0.71
HD3040	37±8.77	43±4.38	4.2±1.29	7.6±1.12	19.4±0.99	19.4±0.99
HI1563	52±1.84	50±0.42	7.3±0.93	8.3±1.63	20.2±1.56	17±0.71
HI1571	58±6.08	50±0.57	7.4±1.02	8.1±1.48	17.4±0.42	18.4±0.28
HI8703	51±1.27	41±5.80	9.7±0.03	7.2±0.86	20.2±1.56	18.2±0.14
HI8704	48±0.57	34±10.32	8.1±1.51	6.2±0.15	17.8±0.14	18±0.00
HUW234	49±0.19	52±1.84	7.1±0.77	9.6±2.57	19.8±1.27	16.2±1.27
LOK62	48±0.42	49±0.00	9.2±0.25	8.1±1.51	16.6±0.99	18.8±0.57
MP3304	46±2.26	50±0.71	8.5±1.79	9.2±2.26	15.2±1.98	18.2±0.14
MP4010	75±18.38	48±0.71	4.4±1.14	8.3±1.65	18.6±0.42	20.6±1.84
NIAW34	42±4.81	43±4.38	7.3±0.91	9.2±2.26	16.6±0.99	17±0.71
NW2036	42±4.67	42±4.67	8.9±2.02	8.6±1.80	20.2±1.56	17±0.71
PBW373	57±5.80	50±0.42	8.8±1.98	7.5±1.05	19.8±1.27	17±0.71
PBW590	41±5.80	48±0.57	5.5±0.35	6.0±0.02	15.0±2.12	15±2.12
PBW639	45±2.97	52±1.98	6.9±0.61	6.9±0.64	20.6±1.84	20.6±1.84
PDW322	40±6.51	50±0.42	6.4±0.26	9.8±2.65	17.4±0.42	18.2±0.14
RAJ4083	47±1.27	40±6.51	6.3±0.24	8.4±1.66	15.8±1.56	18.6±0.42
UAS320	48±0.42	52±2.12	6.2±0.11	10.6±1.23	20.6±1.84	17.8±0.14
UAS428	38±8.06	38±7.78	7.2±0.83	7.5±1.04	17.4±0.42	18.5±0.35
WH1021	40±6.65	46±1.98	6.1±0.08	9.3±2.31	19.0±0.71	17.8±0.14
WHD946	48±0.99	50±0.42	6.8±0.53	5.8±0.18	21.8±2.69	21.4±2.40
Range	37-75	32-58	3.9-9.7	5.4-10.6	15.0-21.8	15-21.4
Mean	47	45.3	6.8	7.9	18.4	18.2
CD at 5%						
Replications	TS=NS	LS=NS	TS=0.56	LS=1.38	TS=0.22	LS=0.20
Treatments	TS=NS	LS=NS	TS=0.059	LS=1.40	TS= 0.78	LS=0.71

Values are mean±SD of five replicates

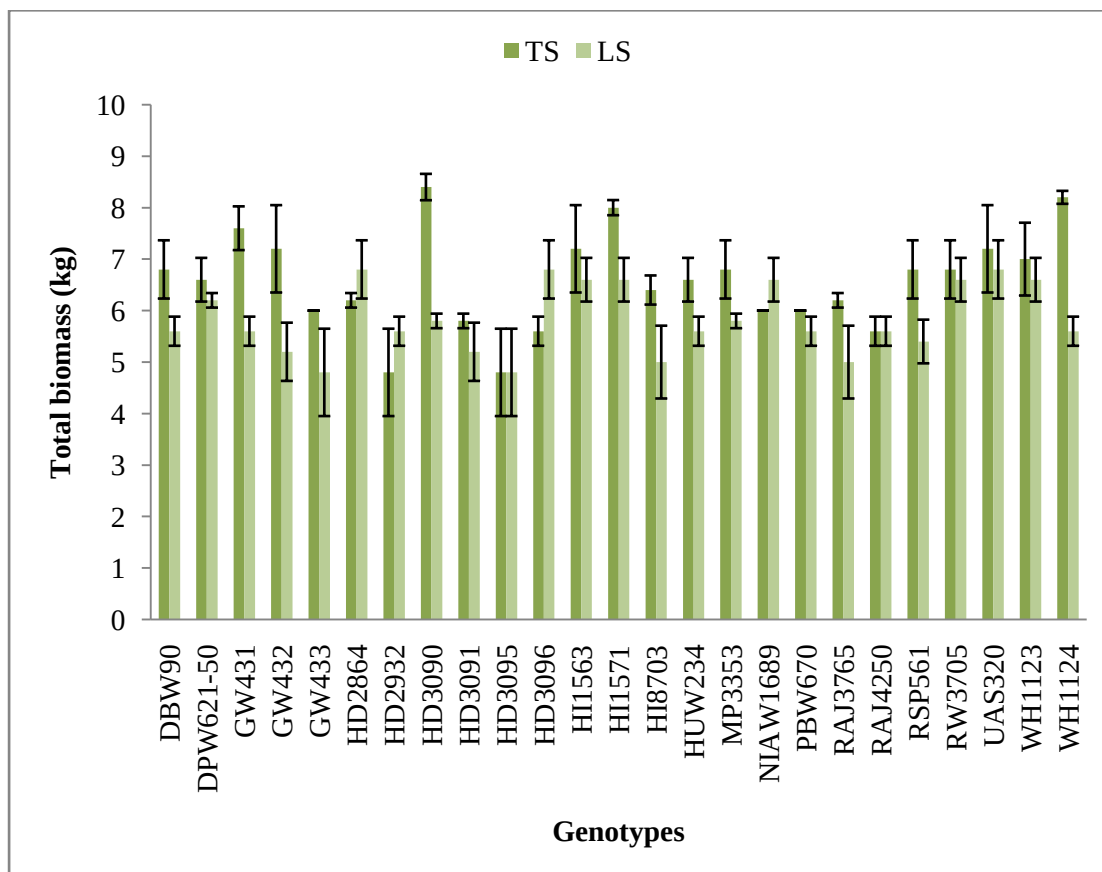


Fig 9a: Total biomass measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

In MLHT-II, total biomass (Table 5b) ranged from 5.4 to 8.0 kg under timely sown conditions and 2.0 to 5.4 kg under late sown conditions with mean values of 6.7 and 3.5 kg respectively.

Genotypes NIAW 34, PBW 639, UAS 320, WH 1021 and WHD 946 had higher biomass under timely sown conditions and genotypes HI 8703, HUW 234, PBW 373, UAS 320 and WH 1021 had higher total biomass under late sown conditions.

All genotypes showed decreased total biomass under late sown conditions. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

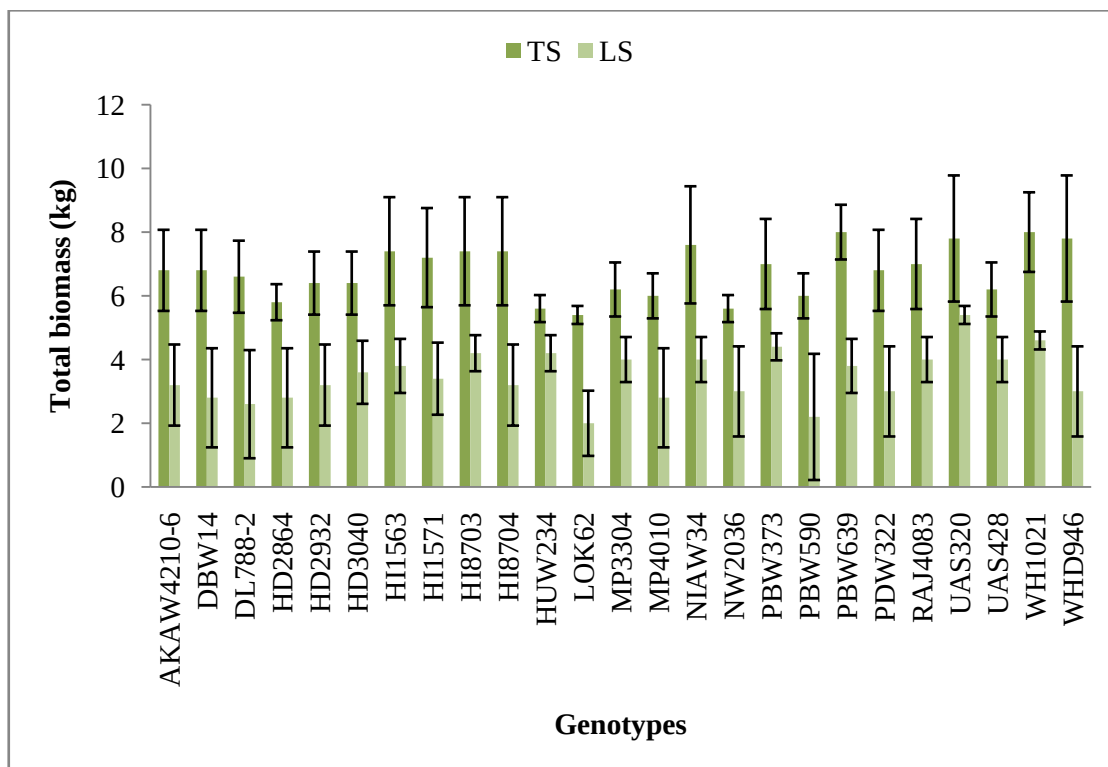


Fig 9b: Total biomass measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

4.1.10 Grain Yield

In MLHT-I, grain yield (Table 5a) ranged from 405 to 560 gm/m² under timely sown and 294 to 465 gm/m² under late sown conditions with mean values of 477 and 380 gm/m² or timely and late sown conditions respectively. Genotypes DBW 90, DPW 621-50 and UAS 320 had higher yield under timely sown conditions. Genotypes GW 433, HD 3090, UAS 320 and WH 1124 had higher yield under late sown conditions.

Genotype UAS 320 was the highest yielded under late sown conditions. Genotypes such as DBW 90, GW 433, HD 2932, WH 1123 and WH 1124 had also high yield and showed tolerant behavior under heat stress. The grain yield was observed to be decreased under late sown conditions for all the genotypes except WH 1124 which yielded equal under both timely and late sown conditions.

In MLHT-II, grain yield (Table 5b) ranged from 347 to 567 gm/m² and 310 to 470 gm/m² with mean values of 455 and 377 gm/m² for timely and late sown conditions, respectively. Genotypes HD 2932, HUW 234, NW 2036 and PBW 639 had high yield under timely sown conditions. Genotypes HD 2932, HI 1563 and NW 2036 had high yield under late sown conditions.

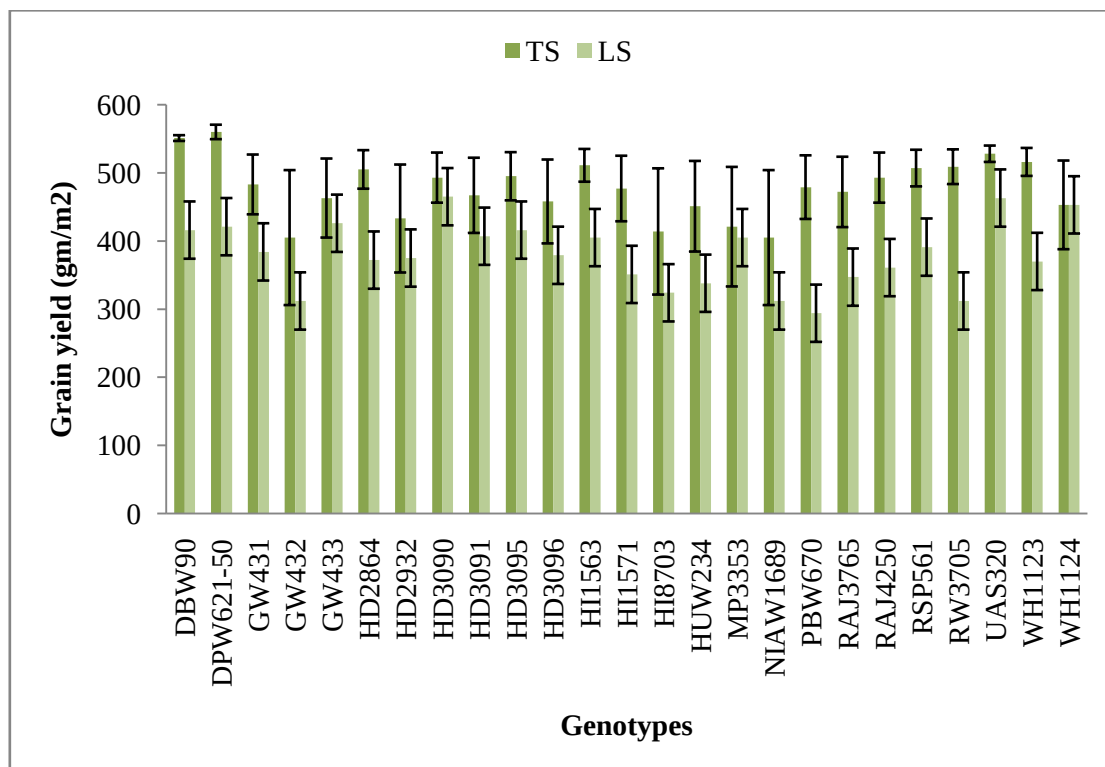


Fig 10a: Grain yield measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

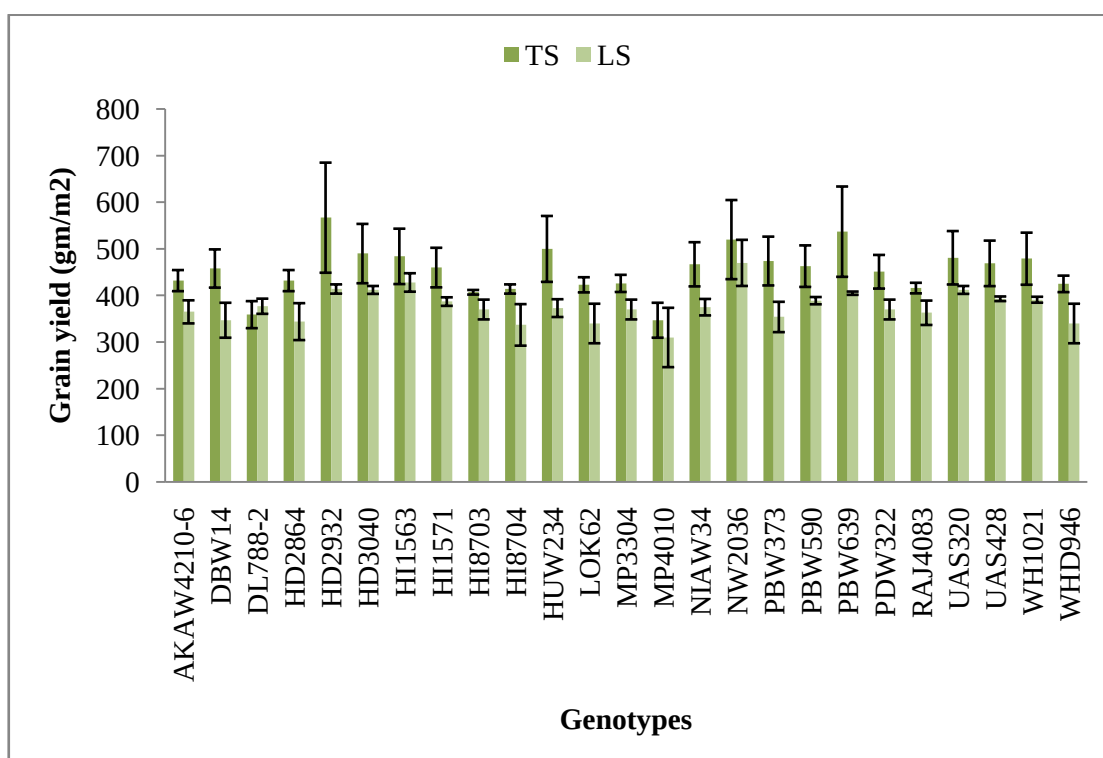


Fig 10b: Grain yield measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

Genotype NW 2036 had maximum yield under late sown conditions. Genotypes such as HD 2932, HD 3040, HI 1563, RAJ 4083 and UAS 320 were also high yielded. Under late sown conditions the grain yield of all genotypes was decreased except DL 788-2. It is found to be significant ($p<0.05$) in the trial MLHT I.

Overall total biomass (Fig 9a, b) and grain yield (Fig 10a, b) was decreased under late sown conditions in all the genotypes indicated the adverse effect of high temperature stress on wheat crop. Reduction in grain yield due to higher temperature conditions in late sown was also observed by Kheiralla and Sherif (1992) and Singh and Ahmad (1997).

4.1.11 Heat Susceptibility Index

Heat susceptibility index (Table 5a) explains the susceptibility of test genotypes to temperature stress environments in relation to normal environment. This trait is effective when genotypes are tested under environments, which differ significantly in temperature regimes or magnitude of high temperature stress. In MLHT-I (Fig 11a), heat susceptibility index ranged from 0 to 1.9 with mean value of 1.0.

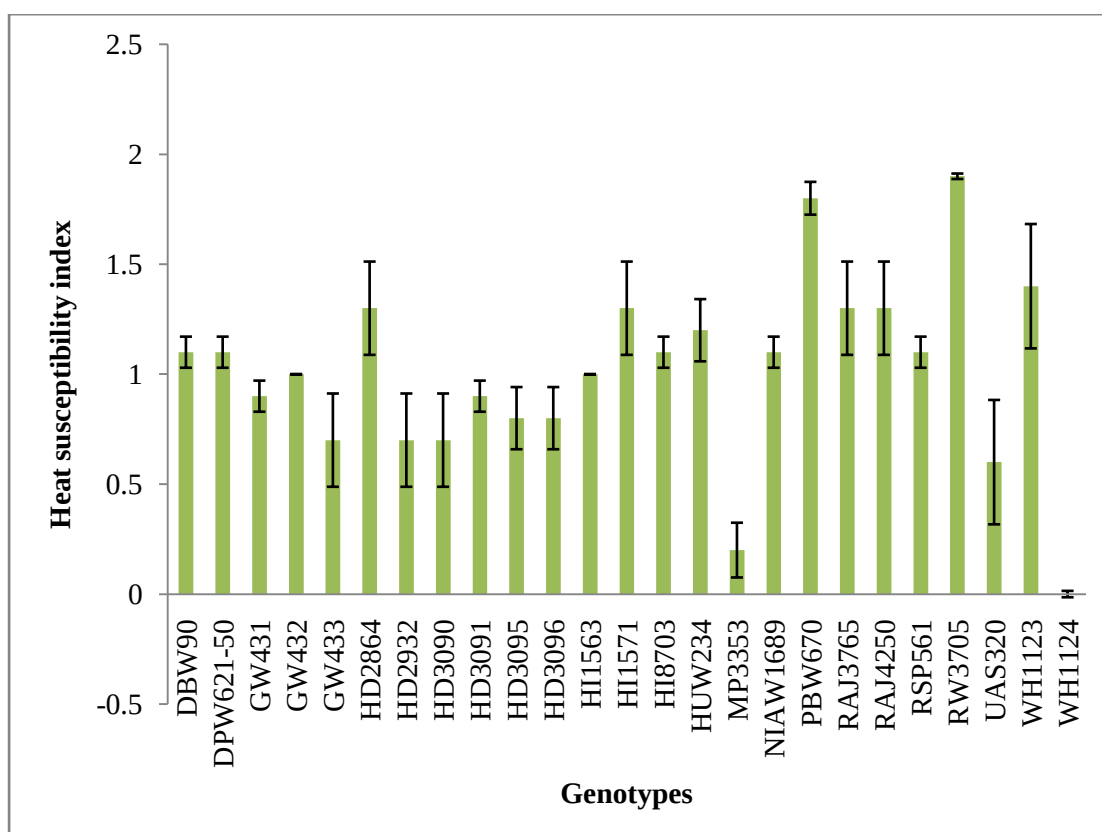


Fig 11a: Heat susceptibility index measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

Table 5a: Total biomass, grain yield and heat susceptibility index measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT I

Genotype	Total biomass (kg)		Grain yield (gm/m ²)		Heat susceptibility index
	TS	LS	TS	LS	
DBW90	6.8±0.57	5.6±0.28	551±4.24	416±91.22	1.1±0.07
DPW621-50	6.6±0.42	6.2±0.14	560±10.61	421±87.68	1.1±0.07
GW431	7.6±0.43	5.6±0.28	483±43.84	384±113.84	0.9±0.07
GW432	7.2±0.85	5.2±0.57	405±98.99	312±164.76	1±0.00
GW433	6±0.00	4.8±0.85	463±57.98	426±84.15	0. 7±0.21
HD2864	6.2±0.14	6.8±0.57	505±28.28	372±122.33	1.3±0.21
HD2932	4.8±0.85	5.6±0.28	433±79.20	375±120.21	0.7±0.21
HD3090	8.4±0.26	5.8±0.14	493±36.77	465±56.57	0.7±0.21
HD3091	5.8±0.14	5.2±0.57	467±55.15	407±97.58	0.9±0.07
HD3095	4.8±0.85	4.8±0.85	495±35.36	416±91.22	0.8±0.14
HD3096	5.6±0.28	6.8±0.57	458±61.52	379±117.38	0.8±0.00
HI1563	7.2±0.85	6.6±0.42	511±24.04	405±98.99	1±0.21
HI1571	8±0.15	6.6±0.42	477±48.08	351±137.18	1.3±0.07
HI8703	6.4±0.28	5±0.71	414±92.63	324±156.27	1.1±0.14
HUW234	6.6±0.42	5.6±0.28	451±66.47	338±146.37	1.2±0.14
MP3353	6.8±0.57	5.8±0.14	421±87.68	405±98.99	0.2±0.00
NIAW1689	6±0.00	6.6±0.42	405±98.99	312±164.76	1.1±0.21
PBW670	6±0.00	5.6±0.28	479±46.67	294±177.48	1.8±0.07
RAJ3765	6.2±0.14	5±0.71	472±51.62	347±140.01	1.3±0.14
RAJ4250	5.6±0.28	5.6±0.28	493±36.77	361±130.11	1.3±0.12
RSP561	6.8±0.57	5.4±0.42	507±26.87	391±108.89	1.1±0.07
RW3705	6.8±0.57	6.6±0.42	509±25.46	312±164.76	1.9±0.07
UAS320	7.2±0.85	6.8±0.57	528±12.02	463±57.98	0.6±0.21
WH1123	7±0.71	6.6±0.42	516±20.51	370±123.74	1.4±0.21
WH1124	8.2±0.13	5.6±0.28	453±65.05	453±65.05	0±0.07
Range	4.8-8. 4	4.8-6.8	405-560	294-465	0-1.8
Mean	6.5	5.8	477	380	1
CD at 5% Replications Treatments	TS= 0.12 LS=0.37		TS=1.34 LS=0.95		0.23
	TS=0.44 LS=0.39		TS=4.76 LS=3.37		

Values are mean±SD of five replicates

Table 5b: Total biomass, grain yield and heat susceptibility index measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

Genotype	Total biomass (kg)		Grain yield (gm/m ²)		Heat susceptibility index
	TS	LS	TS	LS	
AKAW4210-6	6.8±1.27	3.2±1.27	432±22.63	365±24.75	0.9±0.07
DBW14	6.8±1.27	2.8±1.56	458±41.01	347±37.48	1.4±0.28
DL788-2	6.6±1.13	2.6±1.70	359±28.99	377±16.26	-0.3±0.01
HD2864	5.8±0.57	2.8±1.56	432±22.63	344±39.60	1.2±0.14
HD2932	6.4±0.99	3.2±1.27	567±118.09	414±9.90	1.6±0.42
HD3040	6.4±0.99	3.6±0.99	490±63.64	412±8.49	0.9±0.07
HI1563	7.4±1.70	3.8±0.85	484±59.40	428±19.80	0.7±0.21
HI1571	7.2±1.56	3.4±1.13	460±42.43	387±9.19	0.9±0.07
HI8703	7.4±1.70	4.2±0.57	407±4.95	370±21.21	0.5±0.02
HI8704	7.4±1.70	3.2±1.27	414±9.90	337±44.55	1±0.00
HUW234	5.6±0.42	4.2±0.57	500±70.71	373±19.09	1.5±0.35
LOK62	5.4±0.28	2±1.02	423±16.26	340±42.43	1.1±0.07
MP3304	6.2±0.85	4±0.71	426±18.38	370±21.21	0.8±0.14
MP4010	6±0.71	2.8±1.56	347±37.48	310±63.64	0.6±0.28
NIAW34	7.6±1.84	4±0.71	467±47.38	375±17.68	1.1±0.07
NW2036	5.6±0.42	3±1.41	520±84.85	470±49.50	0.6±0.28
PBW373	7±1.41	4.4±0.42	474±52.33	354±32.53	1.5±0.04
PBW590	6±0.71	2.2±1.98	463±44.55	389±7.78	0.9±0.07
PBW639	8±0.86	3.8±0.85	537±96.87	405±3.54	1.4±0.28
PDW322	6.8±1.27	3±1.41	451±36.06	370±21.21	1±0.00
RAJ4083	7±1.41	4±0.71	416±11.31	363±26.16	0.7±0.21
UAS320	7.8±1.98	5.4±0.28	481±57.28	412±8.49	0.8±0.14
UAS428	6.2±0.85	4±0.71	469±48.79	393±4.95	0.9±0.07
WH1021	8±1.25	4.6±0.28	479±55.86	391±6.36	1.2±0.14
WHD946	7.8±1.98	3±1.41	425±17.68	340±42.43	1.1±0.07
Range	5.4-8	2-5.4	347-567	310-470	-0.3-1.6
Mean	6.7	3.5	455	377	1.0
CD at 5% Replications Treatments	TS= 0.80 LS=0.51 TS=0.80 LS=0.53		TS=NS LS=2.36 TS=NS LS=8.37		0.34

Values are mean±SD of five replicates

Genotypes such as GW 433, HD 2932, HD 3090, MP 3353, UAS 320 and WH 1124 were found to be less susceptible to thermal regimes that prevailed under late sown conditions.

In MLHT II (Fig 11b), heat susceptibility index (Table 5b) ranged from -0.3 to 1.6 with mean value of 1.0. Genotypes DL 788-2, HI 1563, HI 8703, HD 3040, MP 3304, NW 2036 and RAJ 4083 were found to be less susceptible to thermal regimes that prevailed under late sown conditions. It is found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

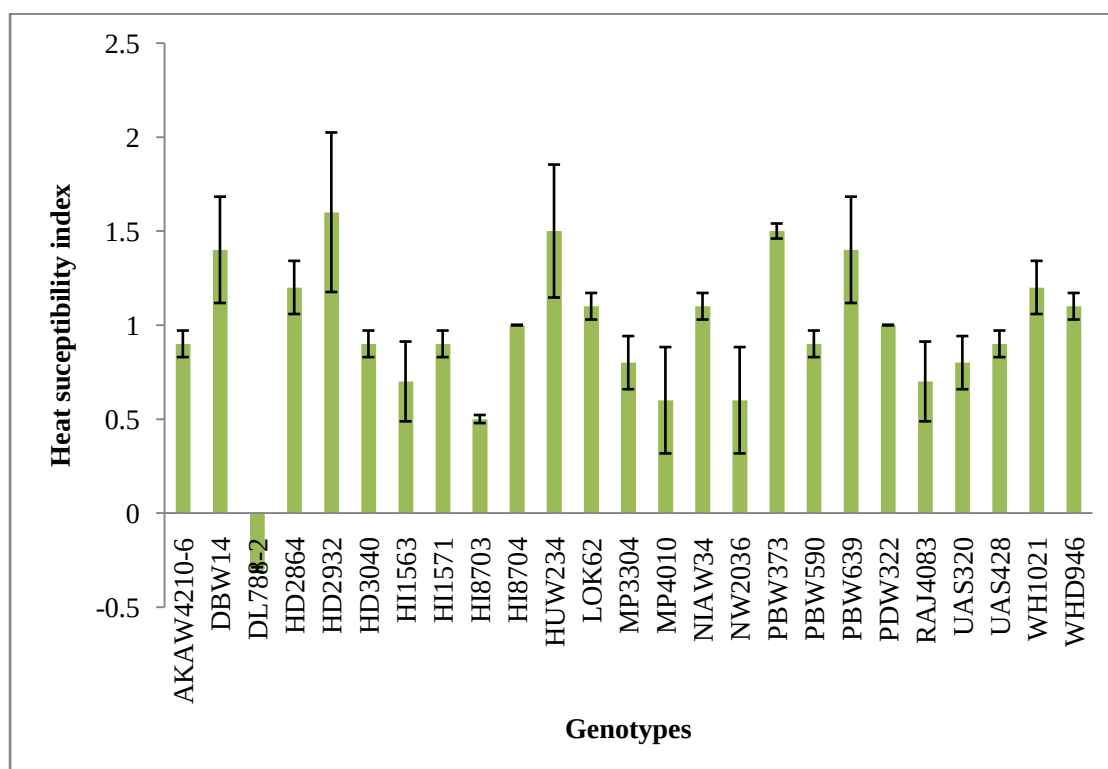


Fig 11b: Heat susceptibility index measured after harvesting in wheat genotypes under timely and late sown conditions in MLHT II

4.2 Antioxidative defense system

4.2.1 Superoxide dismutase (SOD)

In MLHT-I, tolerant entries GW 433, HD 3090 and MP 3353 had higher enzyme activity for timely sown condition than late sown condition except WH 1124 (Table 6a). Specific activity of GW 433, HD 3090 and MP 3353 found to be relatively same to each other for both timely and late sown conditions except WH 1124 which had higher specific activity for timely sown than late sown conditions.

All the susceptible entries HI 1571, PBW 670, RAJ 4250 and WH 1123 had higher activity for timely sown conditions than late sown conditions. For checks, the HD 2932, RW 3705 and RAJ 3765 had higher enzyme and specific activity than HD 2864 and UAS 5320 as

well as late sown conditions. This implies SOD activity is affected by the heat stress.

In MLHT – II, all the three tolerant genotypes HD 3040, HI 8703 and MP 3304 had higher enzyme activity (Table 6b) as well as specific activity for late sown conditions than timely sown conditions. The susceptible entries HI 8704, PBW 639 and WHD 946 showed higher enzyme activity for timely sown condition than late sown conditions.

Table 6a: Activity of superoxide dismutase (SOD) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Superoxide dismutase	
		TS	LS
Tolerant entries	GW433	304.61±12.49 (26.69±2.13)	276.92±19.58 (26.39±3.55)
	HD3090	322.28±12.49 (21.08±1.68)	276.92±12.07 (18.34±3.93)
	MP3353	304.61±12.49 (18.38±1.47)	276.93±0.01 (19.22±0.01)
	WH1124	301.61±2.12 (19.19±0.27)	302.58±13.93 (14.33±1.28)
Susceptible entries	HI1571	322.26±0.01 (23.10±0.00)	302.21±14.19 (13.85±1.26)
	PBW670	322.22±0.04 (22.22±0.01)	276.92±19.58 (13.83±2.06)
	RAJ4250	322.21±12.45 (11.19±0.89)	304.61±19.58 (15.65±2.11)
	WH1123	322.28±15.65 (22.54±8.15)	304.61±19.58 (17.55 ± 2.36)
Checks	HD2864	304.61±12.49 (30.45±2.43)	276.92 ± 19.58 (17.48 ± 2.35)
	HD2932	322.28±12.49 (28.69±2.29)	304.59±0.01 (11.80±0.01)
	RAJ3765	322.28±12.49 (27.59±2.20)	304.59±0.01 (25.68±0.02)
	RW3705	322.28±12.49 (19.83±1.58)	304.63±0.01 (26.19±0.01)
	UAS320	304.61±19.58 (25.42±3.42)	276.92±19.58 (14.22±1.91)
CD at 5% Treatments	TS=3.09,LS=2.21		

Values without parenthesis are enzyme activities expressed as SOD units per g of DW. Values in parenthesis are specific activities expressed as SOD units per mg of proteins. Values are mean ± SD of three replicates.

Table 6b: Activity of superoxide dismutase (SOD) in grains of wheat genotypes under timely and late sown conditions MLHT II

Genotypes		Superoxide dismutase	
		TS	LS
Tolerant entries	HD3040	249.23±8.65 (16.25±3.87)	322.21±0.05 (17.57±0.01)
	HI8703	249.23±8.65 (21.91±7.92)	322.26±0.01 (22.90±0.001)
	MP3304	276.92±19.58 (16.70±2.25)	276.95±0.02 (19.15±0.001)
Susceptible entries	HI8704	322.28±0.18 (25.17±0.03)	304.61±0.05 (29.12±0.01)
	PBW639	322.28±12.49 (14.55±1.16)	299.56±3.57 (17.98±0.43)
	WHD946	276.92±3.07 (21.17±4.53)	249.28±0.04 (13.68±0.001)
Checks	DBW14	193.85±5.7 (13.93±3.76)	221.54±9.16 (12.81±4.03)
	DL788-2	249.23±8.65 (13.82±2.00)	193.85±9.16 (11.22±3.97)
	HUW234	276.92±3.07 (17.41±3.73)	304.61±8.58 (19.53±2.63)
	MP4010	166.15±11.40 (12.93±1.69)	276.92±8.58 (17.97±2.67)
	NW2036	249.23±8.65 (15.85±1.73)	276.89±0.02 (16.67±0.001)
	PBW373	322.26±0.01 (17.64±0.001)	276.92±19.58 (18.67±2.52)
CD at 5% Treatments	TS=2.21,LS=2.27		

Values without parenthesis are enzyme activities expressed as SOD units per g of DW. Values in parenthesis are specific activities expressed as SOD units per mg of proteins. Values are mean ± SD of three replicates.

In checks, DBW 14, HUW 234, MP 4010 and NW 2036 has higher enzyme activity as well as specific activity for late sown conditions than timely sown conditions and DL 788-2 and PBW 373 has higher enzyme activity for timely sown than late sown conditions.

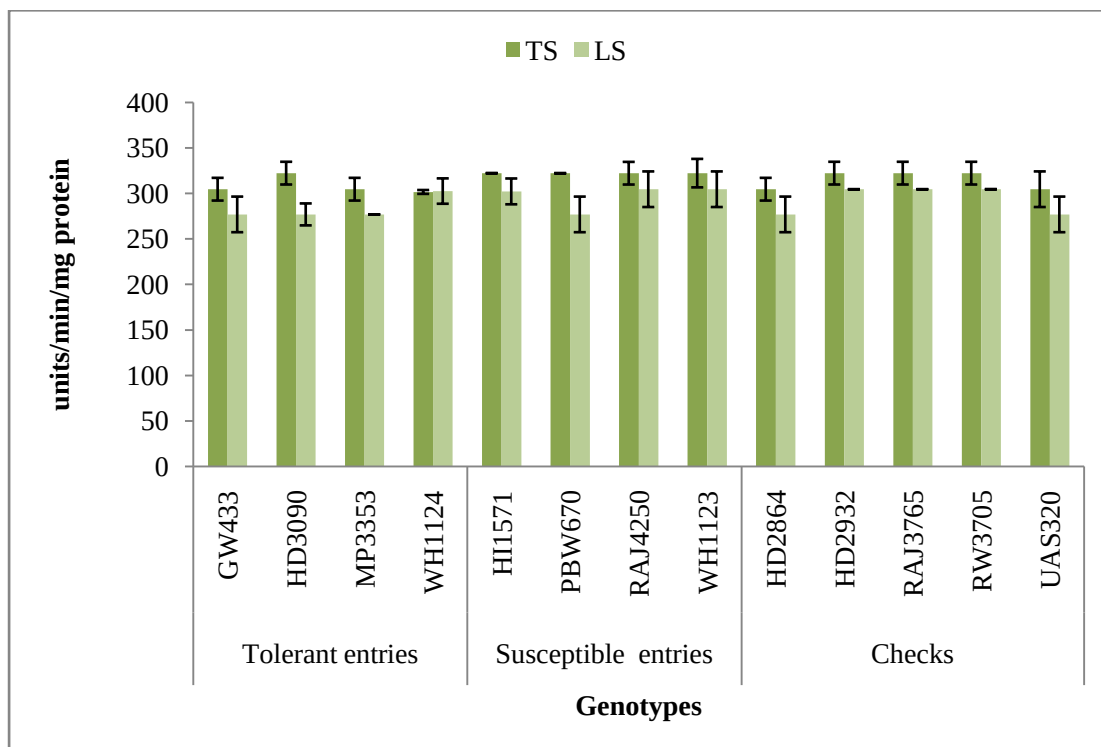


Fig 12a: Activity of superoxide dismutase (SOD) in grains of wheat genotypes under timely and late sown conditions in MLHT I

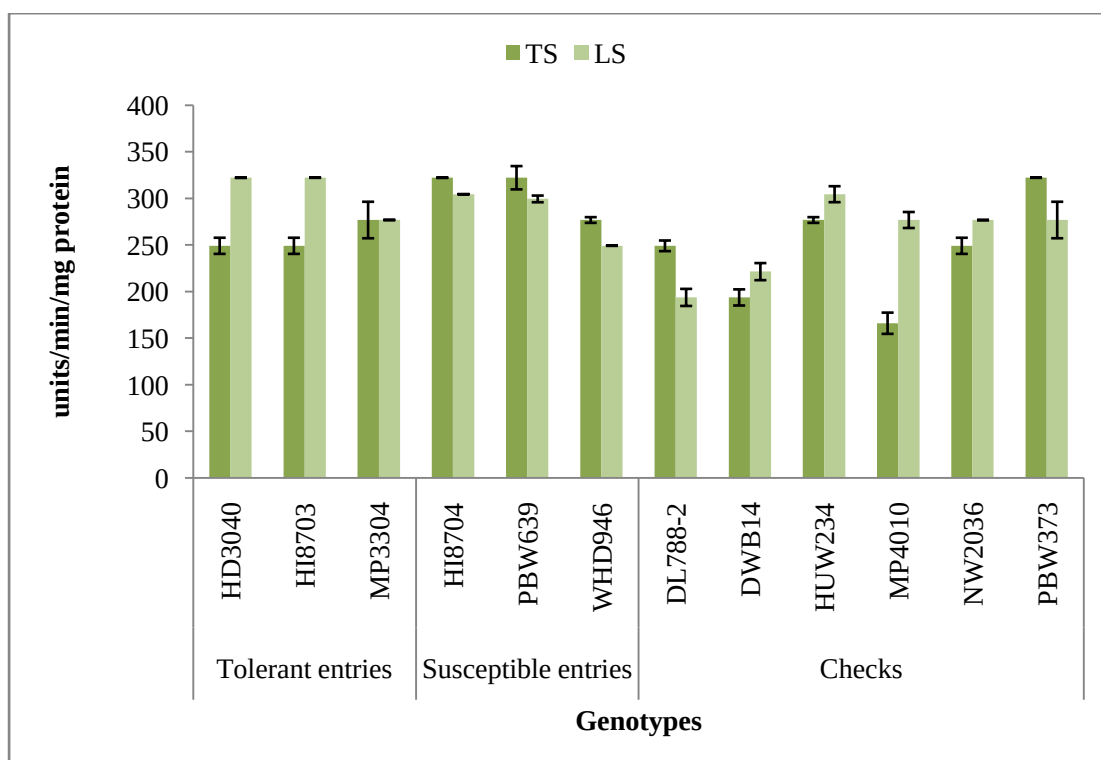


Fig 12b: Activity of superoxide dismutase (SOD) in grains of wheat genotypes under timely and late sown conditions in MLHT II

It implies that genotypes such as WH 1124, HD 3040, HI 8703, MP 3304, DBW 14, HUW 234, MP 4010 and NW2036 showed increased SOD activity (Fig 12a, 12b) under late sown conditions and were found to be tolerant under heat stress. It was found to be significant ($p<0.05$) in both the trials MLHT I and MLHT II.

Superoxide dismutase converts O_2^- to H_2O_2 . The induction of SOD activity could be a consequence of excess O_2^- generation under stress, which also act as a signal for induction of other antioxidant enzymes (Almeselmani *et al* 2006). Increase in SOD activity as a result of heat stress was reported by Jiang and Huang (2001).

4.2.2 Peroxidase (POX)

In MHLT-I, all the tolerant entries GW 433, HD 3090, MP 3353 and WH 1124 had higher enzyme activity (Table 7a) as well as specific activity for late sown conditions than timely sown conditions. The two susceptible entries RAJ 4250 and WH 1123 had also higher enzyme activity as well as specific activity for late sown conditions than timely sown conditions and other HI 1571 and PBW 670 had higher activity for timely sown conditions.

In check varieties, HD 2864, RW 3705, RAJ 3765 and UAS 320 has higher activity for late sown than timely sown conditions except HD 2932. It implies that GW 433, HD 3090, MP 3353 and WH 1124 are better tolerant entries for late sown conditions. In checks HD 2864, RW 3705, RAJ 3765 and UAS 320 has better tolerance under late sown conditions.

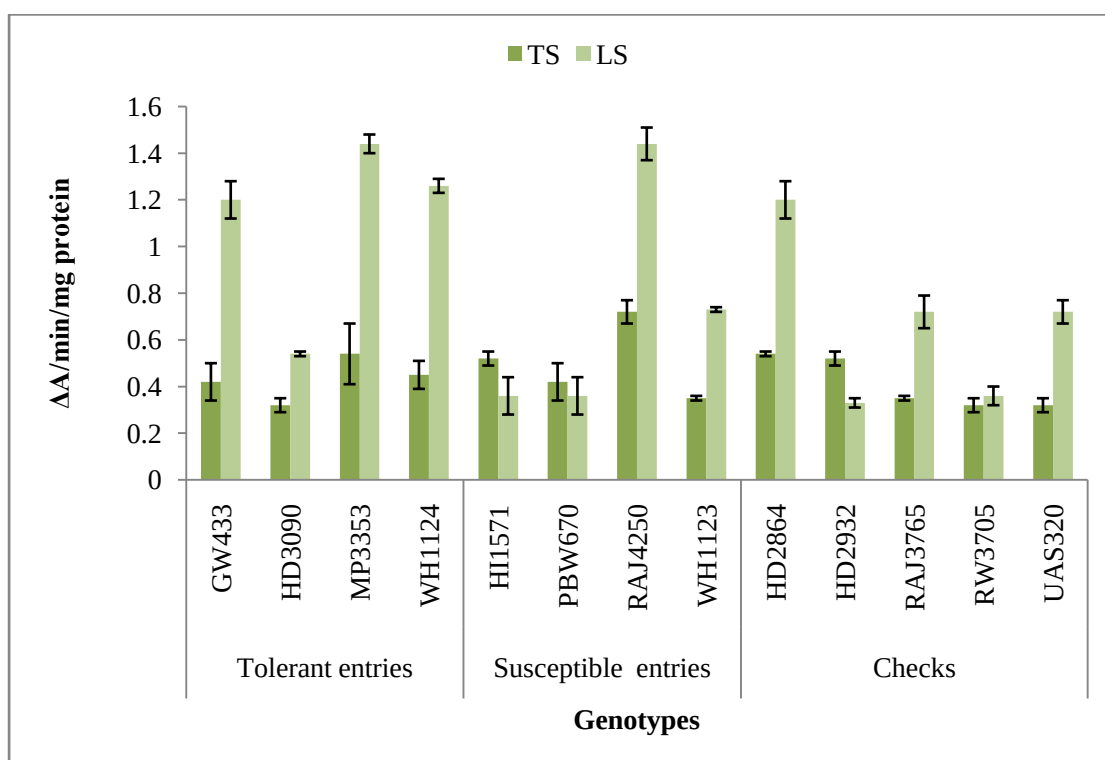


Fig 13a: Activity of peroxidase (POX) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Table 7a: Activity of peroxidase (POX) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Peroxidase	
		TS	LS
Tolerant entries	GW433	0.42 ±0.08 (0.04±0.01)	1.20±0.08 (0.10±0.02)
	HD3090	0.32±0.03 (0.02±0.001)	0.54±0.01 (0.03±0.01)
	MP3353	0.54±0.13 (0.03±0.01)	1.44±0.04 (0.10±0.01)
	WH1124	0.45±0.06 (0.03±0.01)	1.26±0.03 (0.06±0.01)
Susceptible entries	HI1571	0.52±0.03 (0.04±0.002)	0.36±0.08 (0.02±0.01)
	PBW670	0.42±0.08 (0.03±0.01)	0.36±0.08 (0.02±0.01)
	RAJ4250	0.72±0.05 (0.02±0.001)	1.44±0.07 (0.07±0.02)
	WH1123	0.35±0.01 (0.03±0.001)	0.73±0.01 (0.04±0.02)
Checks	HD2864	0.54±0.01 (0.05±0.002)	1.20±0.08 (0.07±0.01)
	HD2932	0.52±0.03 (0.05±0.01)	0.33±0.02 (0.01±0.001)
	RAJ3765	0.35±0.01 (0.03±0.001)	0.72±0.07 (0.05±0.04)
	RW3705	0.32±0.03 (0.02±0.001)	0.36±0.04 (0.04±0.02)
	UAS320	0.32±0.03 (0.03±0.001)	0.72±0.05 (0.03±0.01)
CD at 5% Treatments	TS=0.81,LS=0.17		

Values without parenthesis are enzyme activities expressed as change in absorbance per min per g DW. Values in parenthesis are specific activities expressed as change in absorbance per min per mg of proteins.

Values are mean ± SD of three replicates.

In MLHT – II trial, the HI 8703 and MP 3304 had higher enzyme activity (Table 7b) as well as specificity activity under timely sown conditions and HD 3040 tolerant entry had higher enzyme activity for late sown conditions. In susceptible entries, all the three varieties HI 8704, PBW 639 and WHD 946 and all the check varieties had higher enzyme activity under timely sown conditions than late sown conditions. CAT and GPX are the major antioxidant enzymes. It was found to be significant ($p<0.05$) in both the trials MLHT I and MLHT II.

Table 7b: Activity of peroxidase (POX) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Peroxidase	
		TS	LS
Tolerant entries	HD3040	0.54±0.13 (0.03±0.01)	0.72±0.11 (0.03±0.01)
	HI8703	1.08±0.08 (0.09±0.01)	0.72±0.03 0.05±0.001)
	MP3304	1.02±0.15 (0.06±0.02)	0.54±0.01 0.04±0.001)
Susceptible entries	HI8704	1.08±0.16 (0.08±0.02)	0.22±0.03 (0.02±0.01)
	PBW639	1.46±0.22 (0.06±0.03)	0.19±0.01 (0.01±0.001)
	WHD946	1.86±0.1 (0.32±0.05)	0.19±0.02 (0.01±0.001)
Checks	DBW14	0.61±0.04 (0.03±0.001)	0.20±0.01 (0.01±0.001)
	DL788-2	0.77±0.15 (0.03±0.01)	0.52±0.03 (0.03±0.001)
	HUW234	1.03±0.12 (0.06±0.01)	0.54±0.07 (0.04±0.01)
	MP4010	0.54±0.03 (0.07±0.12)	0.38±0.01 (0.03±0.001)
	NW2036	0.36±0.03 (0.02±0.001)	0.22±0.03 (0.01±0.001)
	PBW373	2.45±0.14 (0.13±0.020)	0.19±0.01 (0.01±0.001)
CD at5% Treatments	TS=0.45,LS=0.56		

Values without parenthesis are enzyme activities expressed as change in absorbance per min per g DW. Values in parenthesis are specific activities expressed as change in absorbance per min per mg of proteins.

Values are mean ± SD of three replicates.

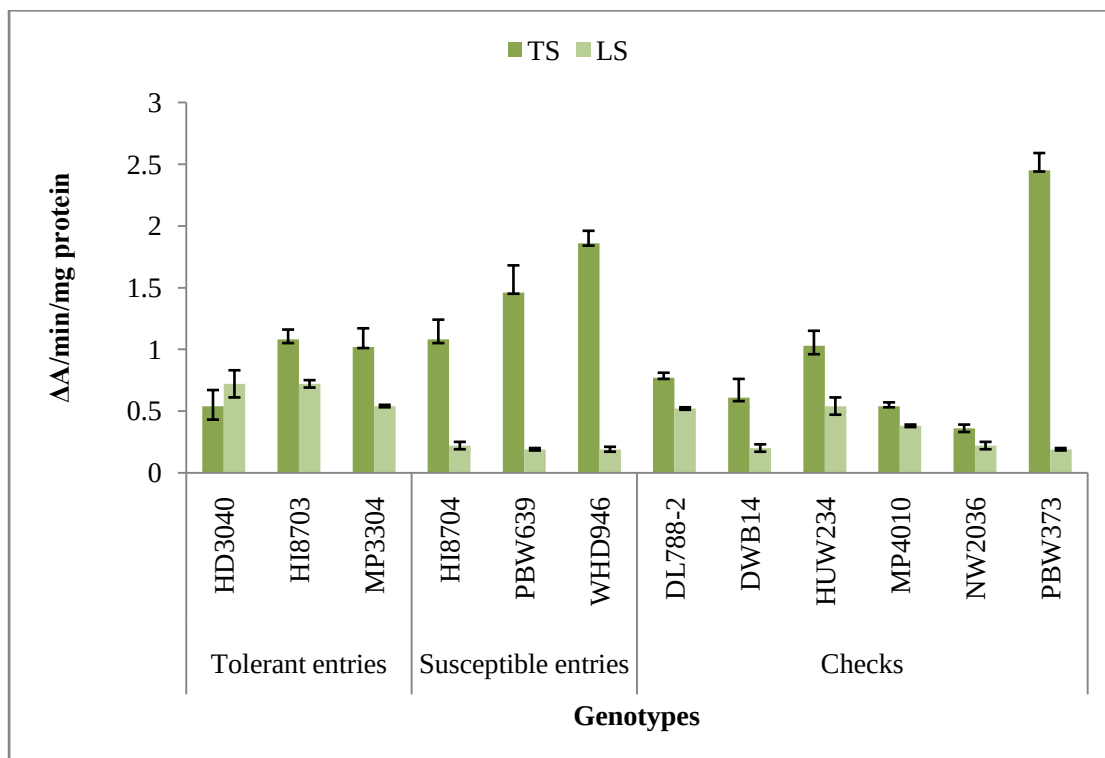


Fig 13b: Activity of peroxidase (POX) in grains of wheat genotypes under timely and late sown conditions in MLHT II

It implies that genotypes such that HD 3040, GW 433, HD 3090, MP 3353, WH 1124, RAJ 4250, WH 1123, HD 2864, RW 3705, RAJ 3765 and UAS 320 had higher POX activity (Fig 13a, 13b) under late sown conditions and were more tolerant to heat stress.

4.2.3 Glutathione reductase (GR)

In MLHT I, in all the varieties whether tolerant entries, susceptible entries and checks, all had higher enzyme activity (Table 8a) as well as specific activity under timely sown conditions than late sown conditions.

In MLHT – II, HD 3040 had higher enzyme activity (Table 8b) under late sown conditions than timely sown conditions and HI 8703, MP 3304 tolerant entry and all the susceptible entry and checks had higher enzyme activity as well as specific activity under timely sown conditions except HI 8704 susceptible entry which has higher activity under late sown conditions. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Table 8a: Activity of glutathione reductase (GR) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Glutathione reductase	
		TS	LS
Tolerant entries	GW433	260.45±0.55 (22.21±0.09)	128.94±5.95 (2.24±1.08)
	HD3090	173.63 ± 10.23 (12.16±1.38)	114.46±10.24 (1.33±1.25)
	MP3353	245.98±3.56 (14.28±0.42)	128.94±4.74 (1.78±0.66)
	WH1124	130.23±10.23 (7.79±1.30)	114.46±10.24 (1.00±0.94)
Susceptible entries	HI1571	300.25±15.94 (22.33±2.29)	136.59±4.82 (1.77±0.43)
	PBW670	159.16±10.23 (10.48±1.41)	177.23±16.95 (3.43±1.78)
	RAJ4250	78.23±6.07 (2.95±0.43)	127.28±1.17 (1.51±0.13)
	WH1123	111.23±3.20 (8.95±0.51)	122.53±4.53 (1.55±0.55)
Checks	HD2864	332.79±0.40 (32.30±0.08)	128.94±10.24 (1.30±1.23)
	HD2932	123.70±4.62 (11.62±0.85)	122.56±4.51 (1.00±0.35)
	RAJ3765	217.04±10.23 (18.47±1.80)	128.50±9.93 (1.81±1.67)
	RW3705	361.74±13.97 (20.92±3.56)	128.98±10.27 (1.87±1.77)
	UAS320	405.14±7.16 (35.86±1.25)	114.46±5.49 (0.90±0.54)
CD at5% Treatments	TS=2.07,LS=0.74		

Values without parenthesis are enzyme activities expressed as n moles of NADP⁺ formed per min per g DW). Values in parenthesis are specific activities expressed as NADP⁺ formed per min per mg of proteins.

Values are mean ± SD of three replicates.

Table 8b: Activity of glutathione reductase (GR) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Glutathione reductase	
		TS	LS
Tolerant entries	HD3040	144.56±4.02 (9.46±1.50)	188.10±3.72 (10.00±0.73)
	HI8703	101.29±4.12 (9.99±2.28)	101.29±1.02 (7.15±0.14)
	MP3304	110.23±3.91 (6.49±0.45)	104.51±0.04 (1.00±0.001)
Susceptible entries	HI8704	46.53±4.08 (4.08±1.25)	101.29±1.30 (9.60±0.25)
	PBW639	186.23±1.32 (8.69±0.12)	114.46±1.02 (1.29±0.12)
	WHD946	126.56±1.68 (1.96±0.24)	122.59±4.49 (1.41±0.49)
Checks	DBW14	144.69±2.27 (7.19±0.54)	128.94±1.02 (1.12±0.05)
	DL788-2	155.28±1.84 (2.74±0.18)	134.51±0.04 (0.73±0.001)
	HUW234	144.69±2.46 (9.25±0.38)	114.51±0.04 (0.97±0.001)
	MP4010	128.94±0.91 (6.86±0.10)	126.54±2.40 (1.93±0.33)
	NW2036	128.94±1.55 (6.38±0.17)	143.41±1.54 (2.55±0.19)
	PBW373	145.26±1.31 (2.43±0.14)	124.52±0.04 (0.93±0.01)
CD at 5% Treatments	TS=1.27.LS=0.59		

Values without parenthesis are enzyme activities expressed as n moles of NADP⁺ formed per min per g DW). Values in parenthesis are specific activities expressed as NADP⁺ formed per min per mg of proteins.

Values are mean ± SD of three replicates.

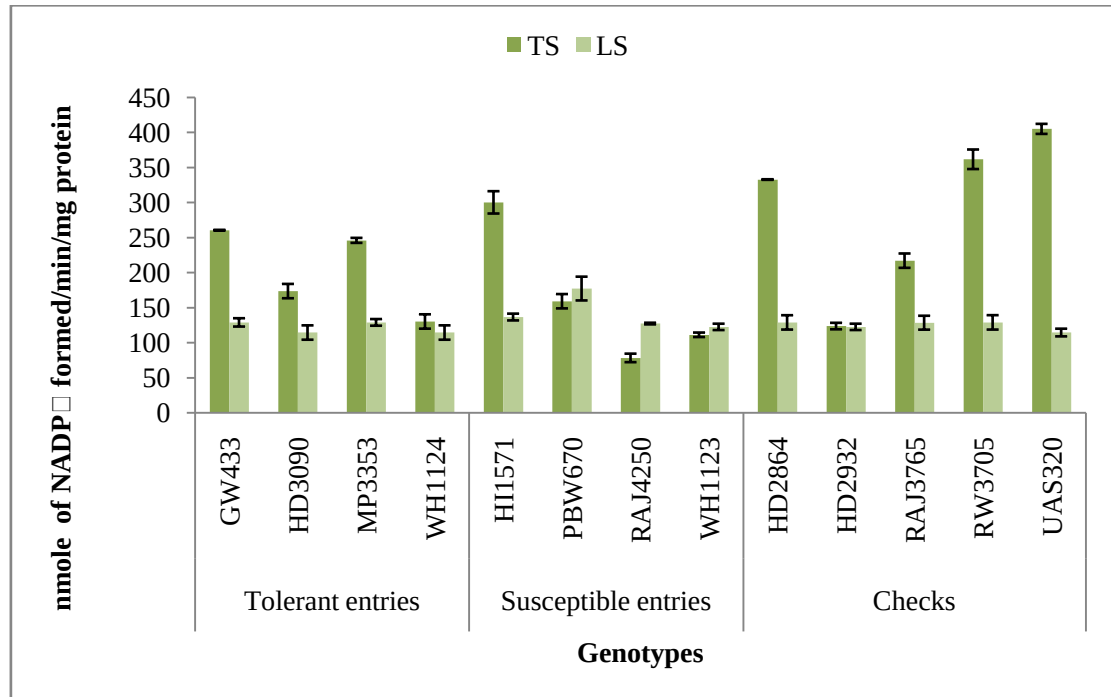


Fig 14a: Activity of glutathione reductase (GR) in grains of wheat genotypes under timely and late sown conditions in MLHT I

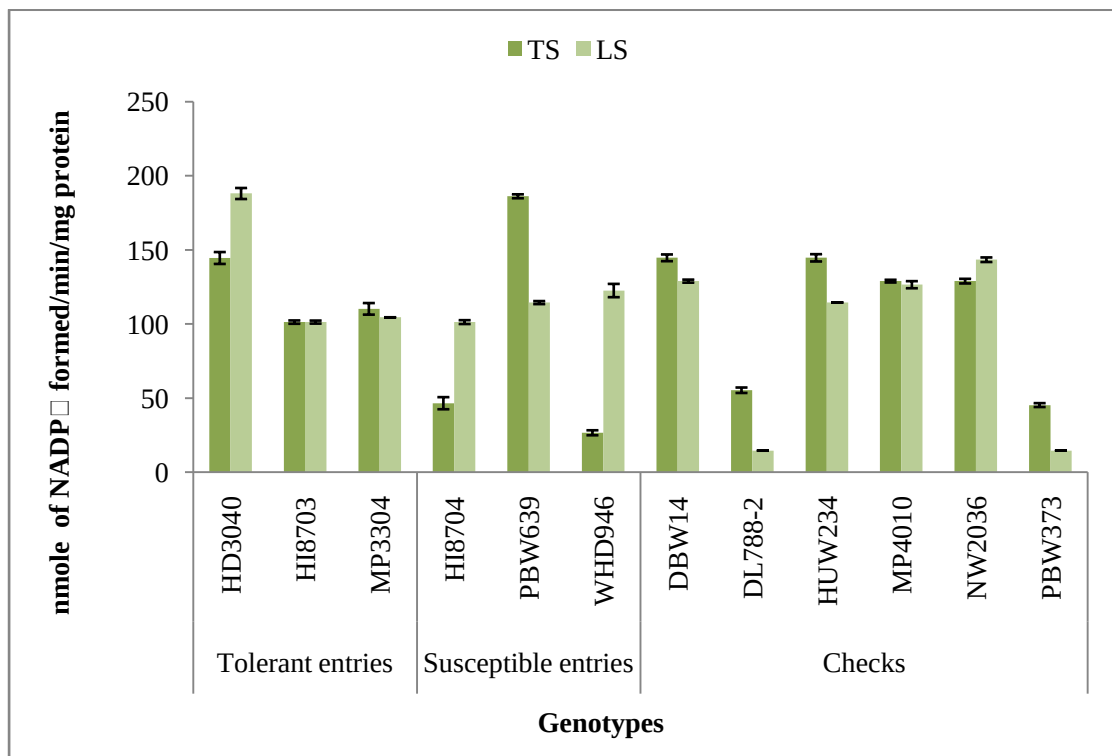


Fig 14b: Activity of glutathione reductase (GR) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Reduction in GR activity (Fig 14a, b) by heat stress was reported by Jiang and Huang (2001). Moreover, heat stress-induced alteration in GR activity was also observed (Foyer *et al* 1994; Gong *et al* 1997).

4.2.4 Ascorbate peroxide (APX)

In MLHT – I, the GW 433, HD 3090 tolerant entries had higher enzyme activity (Table 9a) as well as specific activity under timely sown conditions than late sown conditions and MP 3353, WH 1124 tolerant entries and all the susceptible entries HI 1571, PBW 670, RAJ 4250 and WH 1123 had higher enzyme activity under late sown conditions.

Table 9a: Activity of ascorbate peroxidase (APX) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Ascorbate peroxidase	
		TS	LS
Tolerant entries	GW433	2560.47±33.2 (221.21±9.06)	1853.20±310.36 (148.25±26.33)
	HD3090	1350.00±41.5 (92.95±6.11)	835.70±40.12 (68.85±18.08)
	MP3353	1092.85±45.2 (50.90±3.33)	2250.00±290.94 (127.19±12.05)
	WH1124	1402.54±32.15 (87.13±4.70)	1864.27±159.00 (137.12±14.96)
Susceptible entries	HI1571	2035.02±19.56 (146.67±2.24)	2957.13±181.82 (125.46±16.13)
	PBW670	2250.00±42.26 (158.83±10.34)	2635.70±105.51 (177.44±19.94)
	RAJ4250	1285.70±39.64 (36.72±2.97)	1478.56±154.49 (100.31±18.70)
	WH1123	642.79±40.04 (50.72±0.01)	1414.23±318.23 (98.96±18.42)
Checks	HD2864	2312.56±33.02 (215.35±6.26)	1478.56±309.11 (106.27±19.19)
	HD2932	2314.28±19.02 (207.30±2.82)	1414.28±90.92 (52.29±7.04)
	RAJ3765	864.28±27.21 (74.82±3.56)	2057.13±409.11 (149.06±28.99)
	RW3705	2314.28±19.83 (138.29±3.01)	1707.13±54.48 (93.97±13.81)
	UAS320	1956.12±64.02 (166.98±11.35)	1524.23±47.75 (71.85±7.60)
CD at 5% Treatments	TS=12.78,LS=0.74		

Values without parenthesis are enzyme activities expressed as MDHA formed per min per g DW. Values in parenthesis are specific activities expressed as MDHA formed per min per mg of proteins. Values are mean ± SD of three replicates.

In checks, all the varieties HD 2864, HD 2932, RW 3705 and UAS 320 had higher enzyme activity under timely sown conditions except RAJ 3765 which had higher enzyme activity (Fig 15a) under late sown conditions.

In MLHT II, all the late sown genotypes had higher enzyme activity (Table 9b and Fig 15b) except tolerant entry MP3304, susceptible entry HI 8704 and checks DL 788-2, HUW 234 and PB W373 which had higher enzyme activity under timely sown conditions. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Table 9b: Activity of ascorbate peroxidase (APX) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Ascorbate peroxidase	
		TS	LS
Tolerant entries	HD3040	1414.28±54.56 (98.68±7.68)	2057.13±31.51 (110.95±3.44)
	HI8703	1256.23±24.61 (95±3.77)	1864.27±95.97 (127.68±13.64)
	MP3304	3185.7±61.62 (176.42±18.57)	1202.57±38.58 (15.9±5.34)
Susceptible Entries	HI8704	2123.2±46.72 (163.29±7.30)	1092.58±39.71 (95.01±16.71)
	PBW639	928.56±20.19 (42.45±1.88)	1800±181.83 (99.49±11.65)
	WHD946	892.85±5.06 (63.35±0.71)	1123.45±21.64 (60.82±2.38)
Checks	DBW14	657.13±55.56 (34.54±6.21)	1765.23±71.38 (88.16±7.34)
	DL788-2	2057.13±36.38 (104.19±13.20)	1800±25.26 (90.23±2.56)
	HUW234	1342.85±85.86 (74.5±9.98)	1092.85±25.22 (74.59±3.39)
	MP4010	1664.28±85.52 (91.31±9.06)	1864.27±27.08 (137.34±8.29)
	NW2036	928.55±20.19 (50.71±2.24)	1756.85±75.96 (109±9.15)
	PBW373	1928.25±90.69 (102.03±9.93)	1800±85.87 (111.71±11.03)
CD at 5% Treatments	TS=8.87,LS=15.70		

Values without parenthesis are enzyme activities expressed as MDHA formed per min per g DW. Values in parenthesis are specific activities expressed as MDHA formed per min per mg of proteins. Values are mean ± SD of three replicates.

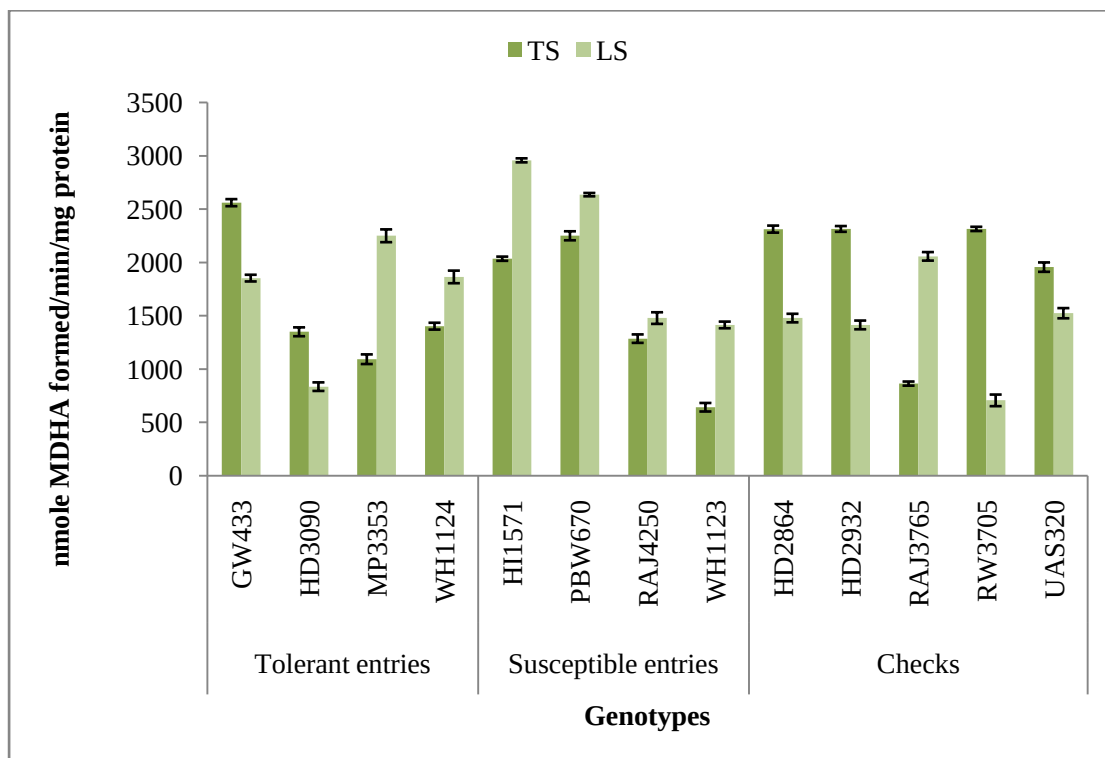


Fig 15a: Activity of ascorbate peroxidase (APX) in grains of wheat genotypes under timely and late sown conditions in MLHT I

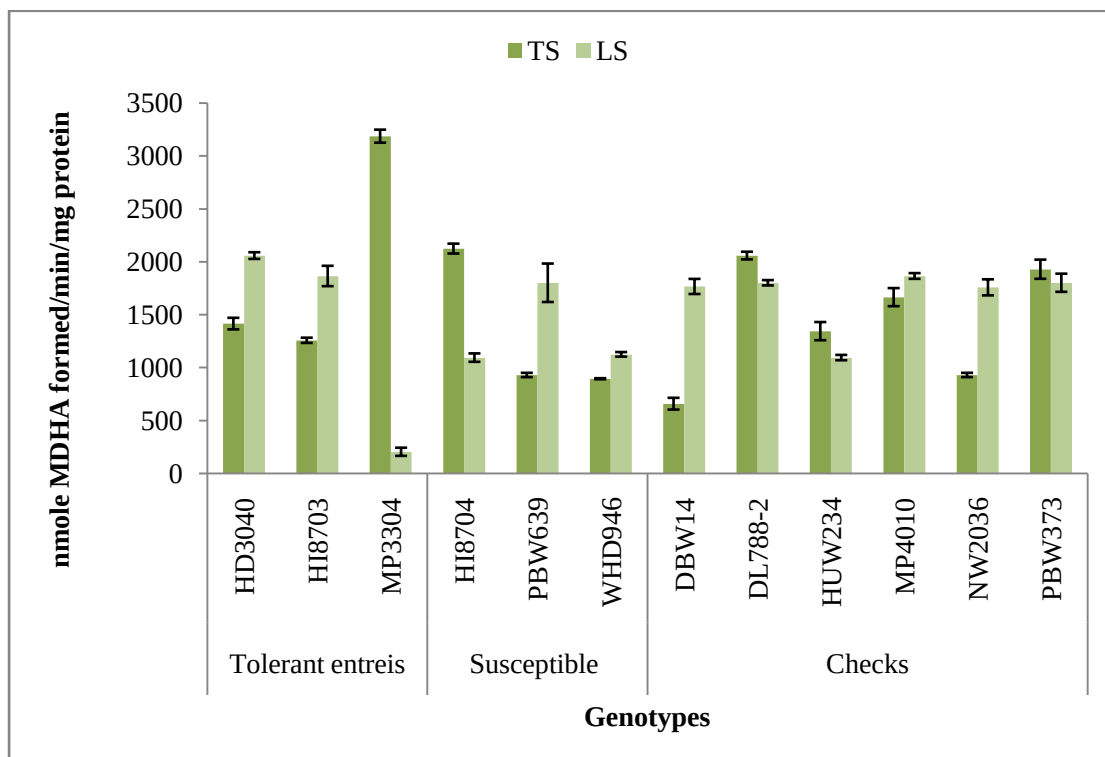


Fig 15b: Activity of ascorbate peroxidase (APX) in grains of wheat genotypes under timely and late sown conditions in MLHT II

The activity of ascorbate peroxidase (uses ascorbate to detoxify hydrogen peroxide) increased at high temperature. The involvement of this enzyme in heat tolerance was previously reported by Koussevitzky (2008) using arabidopsis mutants for APX. Observations of this study regarding increase in APX match with the findings in heat-stressed plants (Sairam *et al* 2000). It has previously been reported that pox (cultivar of blue grass) had significantly higher APX activity at higher temperature (He and Huang 2007).

It implies that the varieties HD 3040 and HI 8703 are better tolerant to heat stress conditions.

4.2.5 Catalase (CAT)

In MLHT I, tolerant entries GW 433, HD 3090 and MP 3353 had higher enzyme activity (Table 10a) as well as specific activity under timely conditions except variety WH 1124 which has higher enzyme activity under late sown conditions. In susceptible entries, HI 1571, RAJ 4250, WH 1123 has higher enzyme activity under timely sown conditions than late sown conditions except PBW 670 which has higher enzyme activity under late sown conditions.

In checks, all the varieties had higher enzyme activity as well as specific activity except UAS 320 which had comparable enzyme activity under timely and late sown conditions.

In MLHT – II out of three tolerant entries two entries i.e. HD 3040, HI 8703 had higher enzyme activity (Table 10b) except MP 3304 which had higher enzyme activity under timely sown conditions. In susceptible entries, PBW 639 and WHD 946 had higher enzyme activity as well as specific activity under timely sown condition and HI 8704 had higher enzyme activity under late sown condition.

In checks, all the varieties had higher enzyme activity under timely sown conditions except DL 788-2, HUW 234 and PBW 373 which had higher enzyme activity under late sown conditions.

It implies that HD 3040, HI 8703, HI 8704, DL 788-2, HUW 234 and PBW 373 are better tolerant (Fig 16a, 16b) to heat stress under late sown conditions. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Table 10a: Activity of catalase (CAT) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Catalase	
		TS	LS
Tolerant entries	GW433	114.21±6.46 (9.34±1.10)	77.66±2.61 (8.50±4.10)
	HD3090	109.64±6.15 (6.61±1.17)	63.96±4.69 (4.33±1.19)
	MP3353	112.23±1.40 (6.64±0.16)	77.66±6.46 (5.07±0.90)
	WH1124	41.12±6.46 (2.89±0.82)	45.68±4.69 (2.41±0.89)
Susceptible entries	HI1571	81.37±2.62 (5.70±0.38)	54.82±2.92 (2.84±1.15)
	PBW670	55.25±5.54 (5.06±0.52)	86.80±2.61 (5.40±1.38)
	RAJ4250	73.09±3.22 (2.53±0.23)	68.53±3.23 (3.56±0.35)
	WH1123	88.95±4.94 (8.98±0.96)	63.96±4.69 (4.26±1.16)
Checks	HD2864	59.39±6.46 (5.02±1.18)	45.68±3.23 (1.86±0.25)
	HD2932	96.52±9.28 (6.52±1.17)	54.82±4.69 (5.30±1.67)
	RAJ3765	105.08±9.69 (8.59±1.69)	91.37±1.99 (4.40±0.19)
	RW3705	86.80±2.93 (8.45±2.28)	77.66±6.46 (6.16±1.09)
	UAS320	77.66±6.46 (5.77±1.02)	77.89±3.07 (4.83±0.37)
CD at 5% Treatments	TS=1.69,LS=1.70		

Values without parenthesis are enzyme activities expressed as μmole of H_2O_2 decomposed per min per g DW. Values in parenthesis are specific activities expressed as μmole of H_2O_2 decomposed per min per mg of proteins.

Values are mean $\pm$ SD of three replicates.

Table 10b: Activity of catalase (CAT) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Catalase	
		TS	LS
Tolerant entries	HD3040	46.56±5.84 (2.88±0.66)	54.82±5.84 (1.99±2.82)
	HI8703	41.12±3.23 (2.98±0.50)	63.96±3.23 (4.38±0.46)
	MP3304	33.71±8.46 (2.28±0.97)	17.82±3.24 (1.88±0.83)
Susceptible entries	HI8704	45.26±2.93 (3.37±0.46)	63.95±0.94 (6.18±0.18)
	PBW639	77.66±4.91 (3.12±0.38)	54.25±2.83 (3.11±0.34)
	WHD946	27.41±6.46 (1.61±0.91)	22.84±6.15 (1.88±0.77)
Checks	DBW14	22.84±5.92 (1.79±0.44)	22.34±6.82 (1.40±0.70)
	DL788-2	27.41±6.46 (1.55±0.63)	91.32±0.04 (4.63±0.001)
	HUW234	47.59±1.88 (2.84±0.22)	49.91±3.47 (3.52±0.47)
	MP4010	82.23±2.60 (4.26±0.27)	46.45±5.92 (3.46±0.81)
	NW2036	65.26±5.54 (3.84±0.61)	50.25±2.69 (2.91±0.32)
	PBW373	73.09±3.16 (4.12±0.35)	82.23±3.23 (5.43±0.42)
CD at 5% Treatments	TS=0.87,LS=1.07		

Values without parenthesis are enzyme activities expressed as μmole of H_2O_2 decomposed per min per g DW. Values in parenthesis are specific activities expressed as μmole of H_2O_2 decomposed per min per mg of proteins.

Values are mean $\pm$ SD of three replicates.

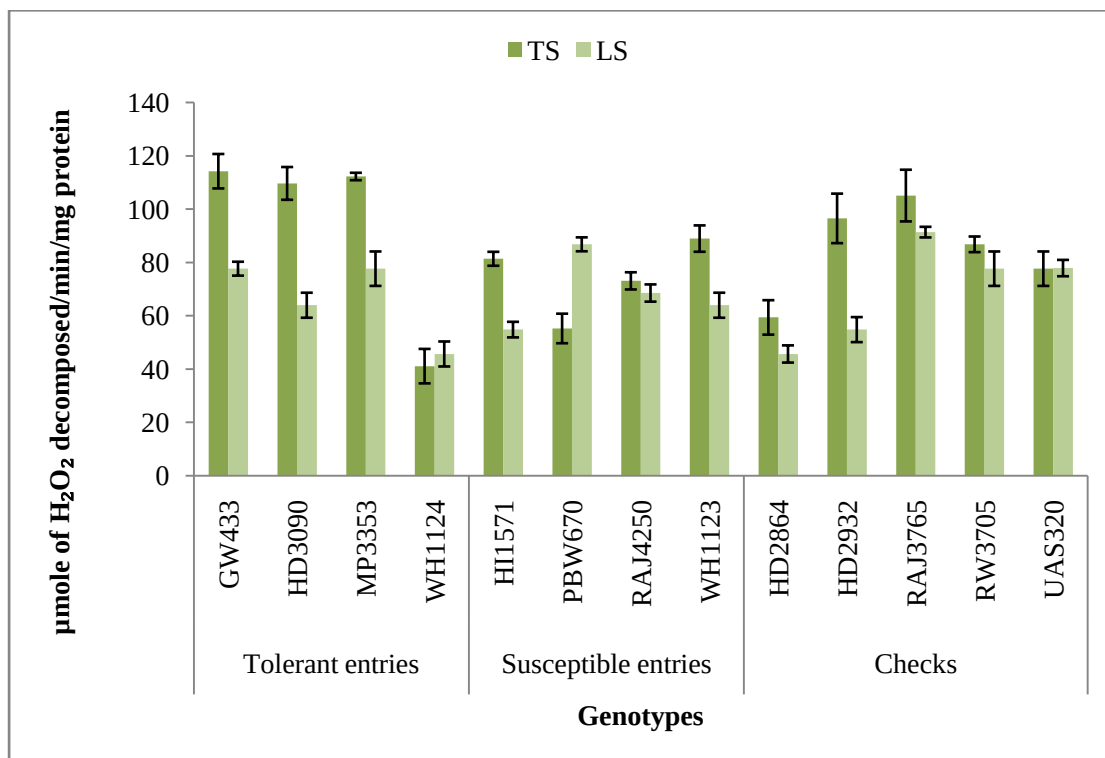


Fig 16a: Activity of catalase (CAT) in grains of wheat genotypes under timely and late sown conditions in MLHT I

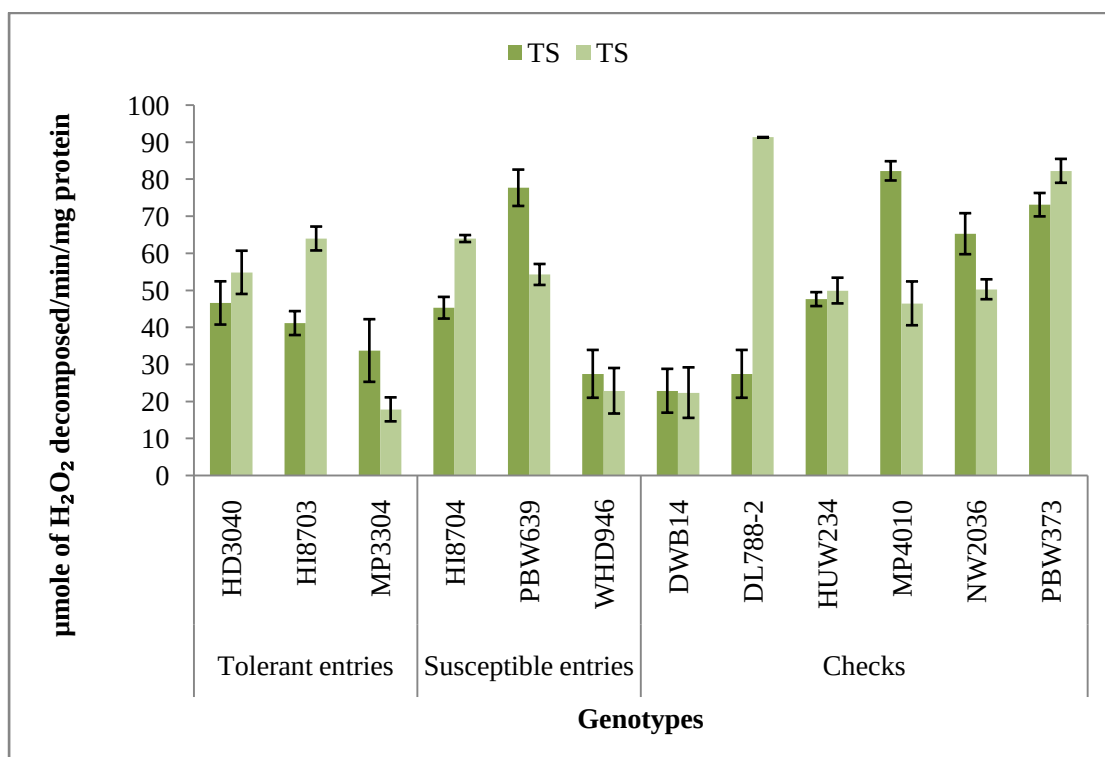


Fig 16b: Activity of catalase (CAT) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Plants with high levels of antioxidants, either constitutive or induced, have been reported to have greater resistance to this oxidative damage (Sudhakar *et al* 2001). Increase in CAT and GPX activity is supposed to be an adaptive trait possibly helping to overcome the damage to the tissue metabolism by reducing toxic levels of H₂O₂ produced during cell metabolism and protection against oxidative stress.

4.2.6 H₂O₂ content

In MLHT – I (Fig 17a), all the varieties GW 433, HD 3090, MP 3353, WH 1124, HI 1571, PBW 670, RAJ 4250, WH 1123, RW 3705, HD 2864, HD 2932 and UAS 320 had higher H₂O₂ content (Table 11a) under timely sown conditions except RAJ 3765 check variety.

In MLHT – II (Fig 17b), all the genotypes HI 8703, MP 3304, HI 8704, PBW 639, DBW 14, DL 788-2, MP 4010, NW 2036 had higher H₂O₂ content (Table 11b) under timely sown condition and tolerant entry HD 3040, susceptible entry WHD 946 and check varieties HUW 234 and PBW 373 had higher H₂O₂ content under late sown conditions. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Table 11a: Content of H₂O₂ (µmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		H ₂ O ₂ content	
		TS	LS
Tolerant entries	GW433	213.00 ± 1.41	110.50 ± 0.71
	HD3090	224.00 ± 4.24	127.00 ± 1.41
	MP3353	261.00 ± 1.41	92.40 ± 0.85
	WH1124	201.00 ± 1.41	113.00 ± 1.41
Susceptible entries	HI1571	289.50 ± 7.78	67.60 ± 1.41
	PBW670	267.00 ± 2.83	183.50 ± 2.12
	RAJ4250	295.50 ± 2.12	105.50 ± 3.54
	WH1123	210.00 ± 1.41	92.35 ± 3.32
Checks	HD2864	240.00 ± 7.07	48.05 ± 2.19
	HD2932	209.50 ± 10.61	126.50 ± 3.54
	RAJ3765	83.23 ± 5.02	111.00 ± 2.83
	RW3705	283.00 ± 4.24	111.00 ± 2.83
	UAS320	203.00 ± 2.83	164.75 ± 0.34
CD at 5% Treatments	TS=10.59,LS=4.96		

Values are mean ± SD of three replicates.

Table 11b: Content of H₂O₂ (µmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		H ₂ O ₂ content	
		TS	LS
Tolerant entries	HD3040	143.77 ± 3.51	155.93 ± 2.35
	HI8703	172.83 ± 2.18	166.13 ± 5.03
	MP3304	277.03 ± 0.66	196.88 ± 7.95
Susceptible entries	HI8704	166.67 ± 2.94	112.75 ± 0.22
	PBW639	230.09 ± 0.75	170.91 ± 0.92
	WHD946	112.86 ± 0.81	124.09 ± 2.16
Checks	DBW14	220.825 ± 2.06	192.34 ± 1.10
	DL788-2	216.185 ± 4.77	172.51 ± 1.30
	HUW234	184.215 ± 1.99	192.36 ± 1.08
	MP4010	215.905 ± 4.38	165.96 ± 6.60
	NW2036	204.00 ± 8.49	162.79 ± 3.50
	PBW373	246.45 ± 5.46	255.16 ± 1.56
CD at 5% Treatments	TS=8.42,LS=8.0		

Values are mean ± SD of three replicates.

Low concentration of H₂O₂ (Wahid *et al* 2007) that quench these oxygen radicals and protect membranes from injurious effects of ROS (Foyer and Noctor 2003). Most of the earlier studies on the effects of multitude of abiotic stresses showed changes in the level of several physiological parameters including lipid peroxidation, H₂O₂ production and proline accumulation in wheat (Georgieva 1999).

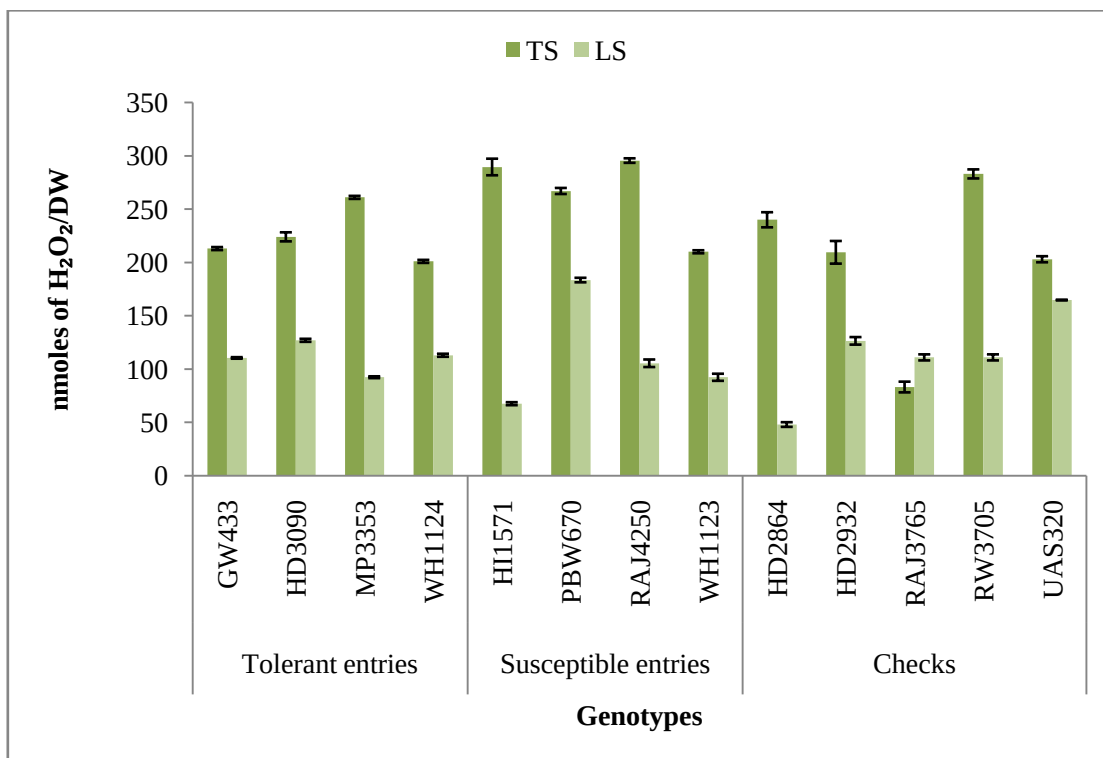


Fig 17a: Content of H_2O_2 (μ mole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT I

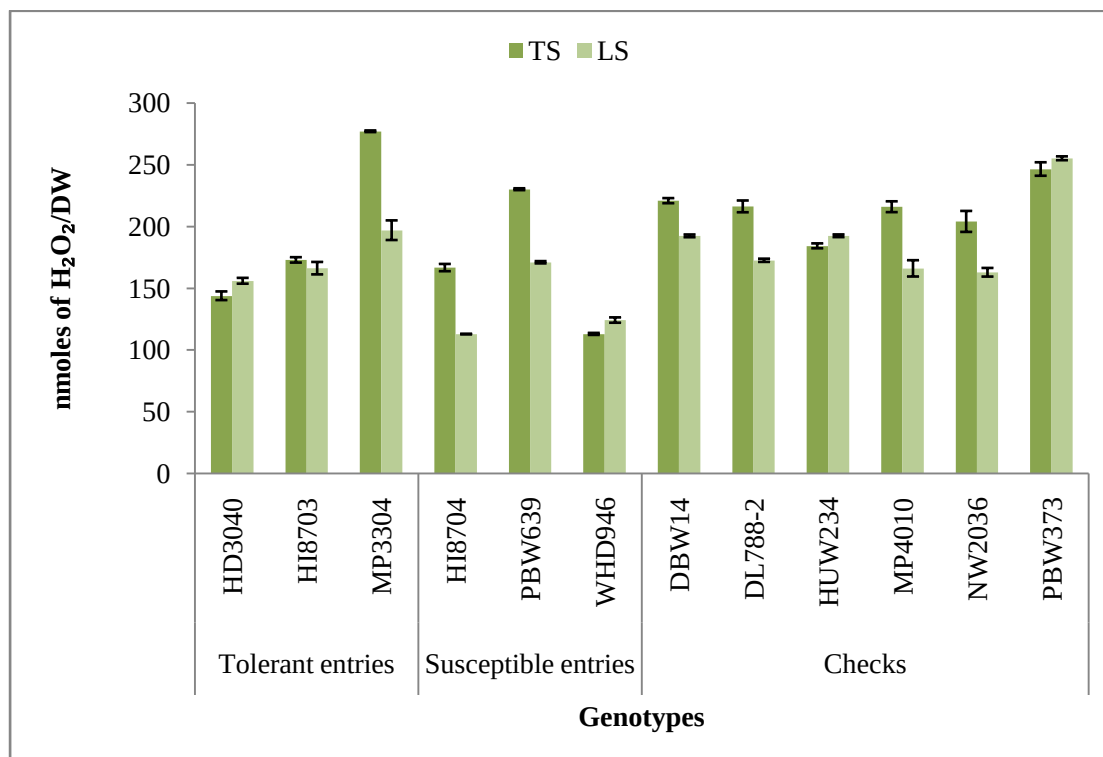


Fig. 17b: Content of H_2O_2 (μ mole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT II

4.2.7 Malondialdehyde (MDA) content

In MLHT – I, MDA content (Table 12a) found higher in all the 13 tolerant entries, susceptible entries and all the checks, under late sown conditions. It implies all the genotypes GWH 33, HD 3090, MP 3353, WH 1124, HI 1571, PBW 670, RAJ 4250, WH 1123, RW 3705, HD2864, HD 2932, RAJ 3765 and UAS 320 were better to curtail lipid peroxidation under late sown conditions. In MLHT – II, all the 12 varieties showed higher MDA content (Table 12b) under late sown condition as MLHT - I. It implies that all the genotypes HD3040, HI 8703, MP 3304, HI 8704, PBW 639, WHD 946, DBW 14, DL 788-2, HUW 234, MP 4010, NW 2036 and PBW 373 had better to curtail lipid per oxidation.

The results showed that MDA level was significantly ($p < 0.05$) increased (Fig 18a, b) under high temperature. There are reports that stresses disrupts membrane permeability by peroxidation of the lipid membrane (Mandhanian *et al* 2006).

Table12a: Content of MDA (nmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		MDA content	
		TS	LS
Tolerant entries	GW433	68.11 ± 11.02	131.70 ± 0.71
	HD3090	74.24 ± 2.40	154.39 ± 2.67
	MP3353	75.58 ± 3.51	234.37 ± 4.76
	WH1124	52.51 ± 5.01	324.01 ± 3.46
Susceptible entries	HI1571	78.77 ± 6.01	218.07 ± 4.31
	PBW670	76.64 ± 14.05	124.48 ± 4.60
	RAJ4250	93.68 ± 2.00	154.26 ± 2.83
	WH1123	75.03 ± 4.28	131.84 ± 3.22
Checks	HD2864	71.67 ± 1.00	139.43 ± 4.01
	HD2932	89.59 ± 0.76	123.96 ± 3.68
	RAJ3765	81.26 ± 5.51	133.59 ± 3.26
	RW3705	59.61 ± 5.05	85.98 ± 3.85
	UAS320	69.19 ± 0.49	221.56 ± 1.41
CD at 5% Treatments	TS=14.9,LS=7.52		

Values are mean ± SD of three replicates.

Table12b: Content of MDA (nmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		MDA content	
		TS	LS
Tolerant entries	HD3040	54.05 ± 3.05	101.92 ± 0.63
	HI8703	48.61 ± 3.51	133.56 ± 1.80
	MP3304	77.42 ± 2.10	82.76 ± 0.63
Susceptible entries	HI8704	44.71 ± 3.00	200.70 ± 0.20
	PBW639	55.45 ± 6.16	80.94 ± 1.94
	WHD946	58.50 ± 1.56	66.36 ± 2.50
Checks	DBW14	114.12 ± 2.20	144.80 ± 4.97
	DL788-2	97.46 ± 2.68	233.60 ± 4.19
	HUW234	59.94 ± 0.53	203.52 ± 3.23
	MP4010	75.68 ± 2.67	124.81 ± 3.13
	NW2036	67.08 ± 3.55	124.79 ± 3.15
	PBW373	61.38 ± 4.51	195.09 ± 4.91
CD at 5% Treatments	TS=7.10,LS=6.62		

Values are mean ± SD of three replicates.

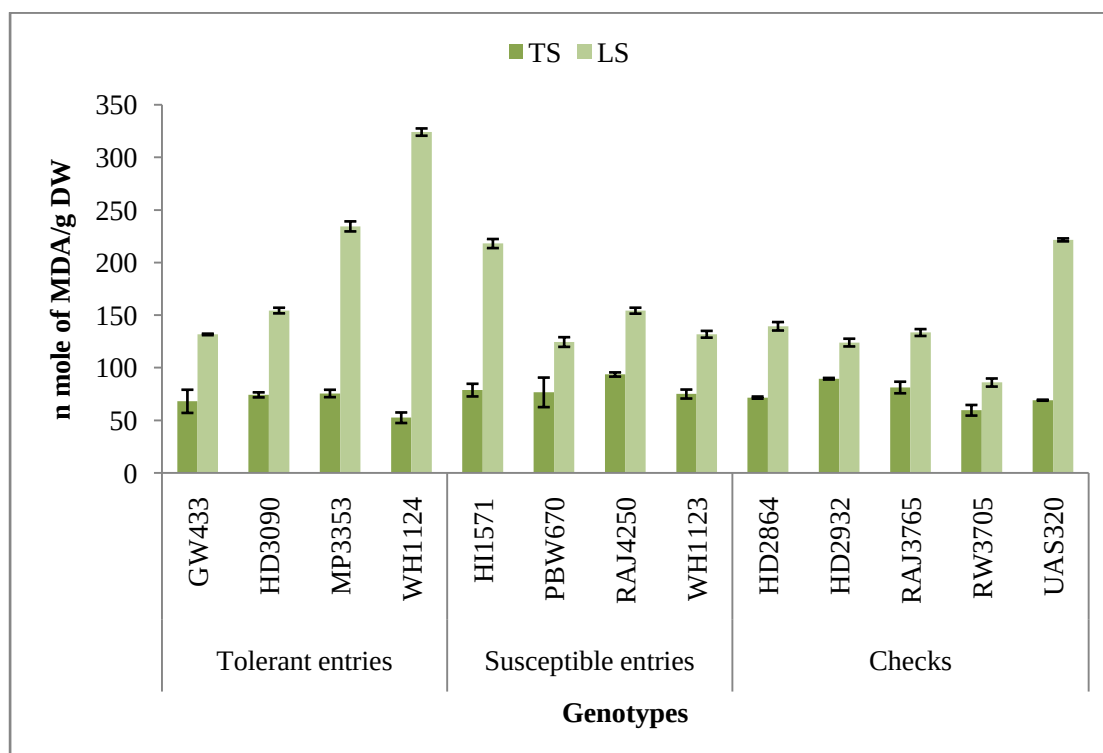


Fig. 18a: Content of MDA (nmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT I

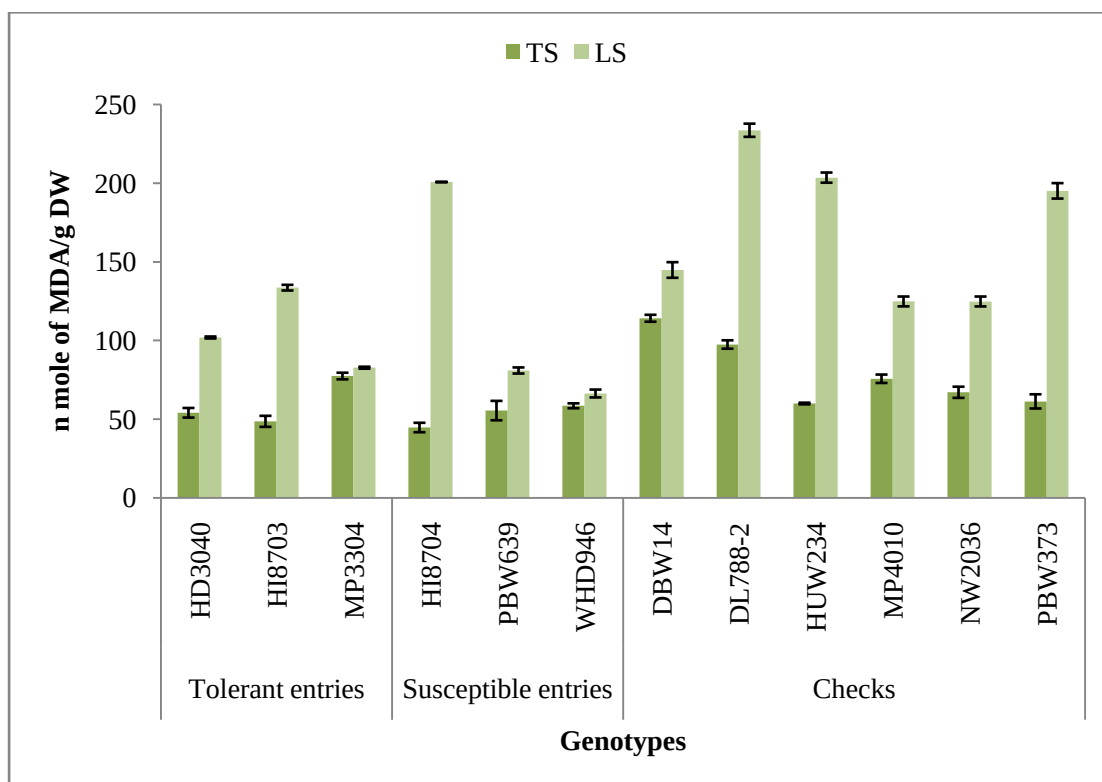


Fig 18b: Content of MDA (nmole per g DW) in grains of wheat genotypes under timely and late sown conditions in MLHT II

4.3 Quality Characteristics

4.3.1 Grain appearance score

In MLHT-I, the grain appearance score (Table 13a) ranged from 5.1 to 5.9 under timely sown varieties and 5.1 to 5.8 under late sown varieties with mean values 5.5 and 5.4, respectively. The grain appearance score was found to be statistically significant. Among the tolerant entries, MP 3353 with highest score 5.9 out of 10 is the best entry. The RAJ 4250 variety is found to be good in grain appearance. Genotypes WH 1124, PBW 670, WH 1123 had score of 5.7 under timely sown conditions which is also good grain appearance score.

MP 3353 with highest 5.8 score was found to be best and stable entry under late sown conditions suggested to have tolerance under high temperature stress. RAJ 4250, HD 2864 and RW 3705 had a score of 5.6 which was found to be good as regards with grain appearance score.

The grain appearance score with mean value 5.5 under timely sown conditions is better than late sown conditions with mean 5.4. So it implies that grain appearance score was affected by heat stress under late sown conditions.

Table 13a: Physical characteristics of grains in wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Grain appearance score (Max. 10)		Test weight (kg/hl)		Grain hardness (kg)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	5.1±0.07	5.4±0.28	73.25±2.30	73.25±2.30	10.34±0.24	10.56±0.40
	HD3090	5.5±0.35	5.5±0.35	75.25±3.71	74.00±2.83	9.71±0.21	9.72±0.20
	MP3353	5.9±0.64	5.8±0.57	76.00±4.24	77.00±4.95	9.12±0.62	8.88±0.79
	WH1124	5.7±0.49	5.2±0.14	74.75±3.36	71.75±1.24	9.68±0.23	7.56±1.73
Susceptible entries	HI1571	5.6±0.42	5.2±0.14	73.50±2.47	72.50±1.77	6.97±2.14	7.25±1.94
	PBW670	5.7±0.49	5.4±0.28	75.50±3.89	76.50±4.60	9.98±0.01	8.98±0.72
	RAJ4250	5.8±0.57	5.6±0.42	77.00±4.95	75.00±3.54	9.14±0.61	7.60±1.70
	WH1123	5.7±0.49	5.4±0.28	75.75±4.07	73.25±2.30	10.68±0.48	8.28±1.22
Checks	HD2864	5.5±0.35	5.6±0.42	71.50±1.06	71.50±1.06	11.01±0.71	7.73±1.61
	HD2932	5.2±0.14	5.1±0.07	74.75±3.36	75.25±3.71	8.41±1.12	8.64±0.96
	RAJ3765	5.5±0.35	5.2±0.14	75.00±3.54	72.58±1.82	9.43±0.40	8.52±1.05
	RW3705	5.5±0.35	5.6±0.42	68.57±1.01	71.50±1.06	10.24±0.17	6.40±2.55
	UAS320	5.1±0.07	5.1±0.07	71.75±1.24	82.70±8.98	8.27±1.22	9.20±0.57
Range		5.1-5.9	5.1-5.8	68.57-77.00	71.50-82.70	6.97-11.01	6.40-10.56
Mean		5.5	5.4	74.04	74.37	9.46	8.41
CD at 5% Treatments	TS=0.16,LS=0.82			TS=1.68,LS=1.86		TS=0.64,LS=0.31	

Values are mean ± SD of three replicates.

Table 13b: Physical characteristics of grains in wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Grain appearance score (Max. 10)		Test weight (kg/hl)		Grain hardness (kg)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	5.8±0.57	5.7±0.49	74.50±0.35	76.75±1.24	6.94±0.04	7.04±0.03
	HI8703	5.4±0.28	5.4±0.28	76.25±0.88	76.50±1.06	8.77±1.25	7.54±0.38
	MP3304	5.5±0.35	5.3±0.21	73.00±1.41	74.75±0.18	8.15±0.81	8.81±1.28
Susceptible entries	HI8704	5.8±0.57	5.6±0.42	78.00±2.12	77.00±1.41	9.10±1.48	7.46±0.33
	PBW639	5.7±0.49	5.4±0.28	74.50±0.35	75.50±0.35	7.24±0.17	8.22±0.86
	WHD946	5.5±0.35	5.5±0.35	73.75±0.88	75.00±0.00	6.61±0.28	6.38±0.44
Checks	DBW14	5.3±0.21	5.3±0.21	74.25±0.53	74.25±0.53	7.32±0.23	7.59±0.42
	DL788-2	5.1±0.07	5.0±0.00	71.25±2.65	71.25±2.65	8.60±1.13	8.13±0.80
	HUW234	5.8±0.57	5.6±0.42	75.25±0.18	73.75±0.88	7.80±0.57	6.47±0.37
	MP4010	5.5±0.35	5.3±0.21	74.00±0.71	74.25±0.53	7.88±0.62	8.31±0.93
	NW2036	5.6±0.42	5.6±0.42	74.75±0.18	76.00±0.71	8.77±1.25	8.24±0.88
	PBW373	5.5±0.35	5.3±0.21	71.00±2.83	71.75±2.30	6.97±0.22	7.10±0.7
Range		5.1-5.8	5.0-5.7	71.00-78.00	71.25-77.00	6.61-9.10	6.38-8.81
Mean		5.5	5.4	74.21	74.73	7.80	7.61
CD at 5% Treatments		TS=0.18,LS=0.14		TS=1.20,LS=1.84		TS=0.47,LS=0.87	

Values are mean ± SD of three replicates.

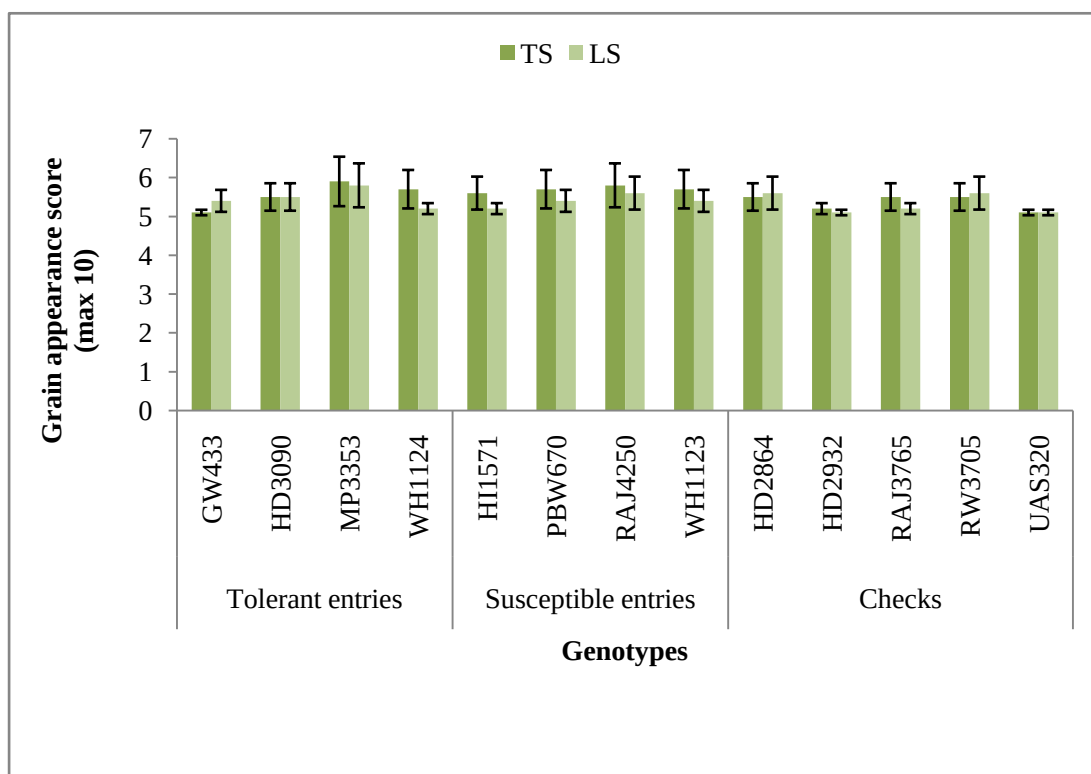


Fig 19a: Grain appearance score of grains in wheat genotypes under timely and late sown conditions in MLHT I

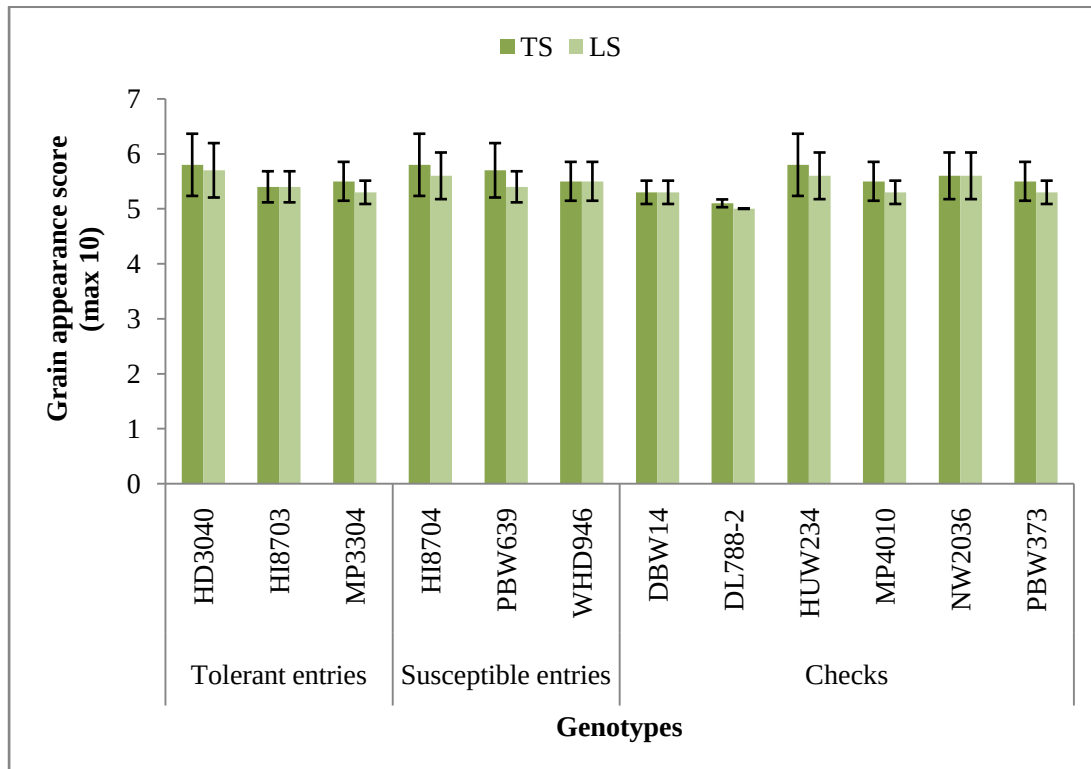


Fig 19b: Grain appearance score of grains in wheat genotypes under timely and late sown conditions in MLHT II

In MLHT-II, the grain appearance score (Table 13b) ranged from 5.15 to 5.8 under timely sown conditions and 5.0 to 5.7 under late sown conditions with mean value of 5.5 and 5.4, respectively. The tolerant entry HD 3040 and susceptible entry HI 8704 and check HUW 234 was found to be best having value of 5.8 under the timely and 5.7, 5.6 and 5.6 under late sown conditions, respectively. HD 3040 was observed to be highest scorer under late sown conditions hence showed its tolerance behavior under high temperature stress.

Overall, the grain appearance score was affected by high temperature stress in both trial MLHT –I and MLHT-II (Fig 19a, b). It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Tasiro and Wardlaw (1990) reported that high temperatures caused shrinking, notching, splitting and chalking of kernels, thus these kernel characteristics affect the end use quality of wheat.

4.3.2 Test Weight

In MLHT-1, the test weight (Table 13a) ranges from 68.57 to 77.00 kg/hl under timely sown conditions and 71.5 to 82.7 kg/hl under late sown conditions with mean values of 74.04 and 74.37 kg/hl, respectively. The test weight shows statistically significant ($p < 0.05$) results.

Under timely sown conditions, the susceptible entry RAJ 4250 found to be the best varieties with value of 77.00 kg/hl whereas RAJ 4250 showed its susceptible behavior with decreased test weight value under late sown conditions. The tolerant entry MP 3353 was found to be good variety with tolerant behavior under high temperature stress conditions. So, it implies that heat stress affect the test weight.

Under late sown conditions, the tolerant entry MP 3353 and susceptible entry PBW 670 also found to be good with values of 77.00 kg/hl and 76.00 kg/hl. The UAS 320 having highest test weight value of 82.70 kg/hl under late sown condition was best among the checks of MLHT I.

In trial MLHT-II, the test weight ranged (Table 13 b) from 71.00 to 78.00 kg/hl for timely sown condition and 71.25 to 77.00 kg/hl under late sown conditions with mean values of 74.25 and 74.73 kg/hl, respectively.

Under timely sown conditions (Fig 20a, b) entry HI 8704 found to be the best entry with test weight value of 78.00 kg/hl. Among late sown conditions, HD 3040, HI 8703 and MP 3304 were observed to have increased test weight under late sown conditions, confirmed their heat tolerance.

Gibson *et al* (1998) reported that changes in kernel characteristics were more pronounced when plants were exposed to sustained temperature of $> 30^{\circ}\text{C}$ during early maturation. They found that high temperature condition during maturation levels caused shriveling of kernels that resulted in reduced test weight.

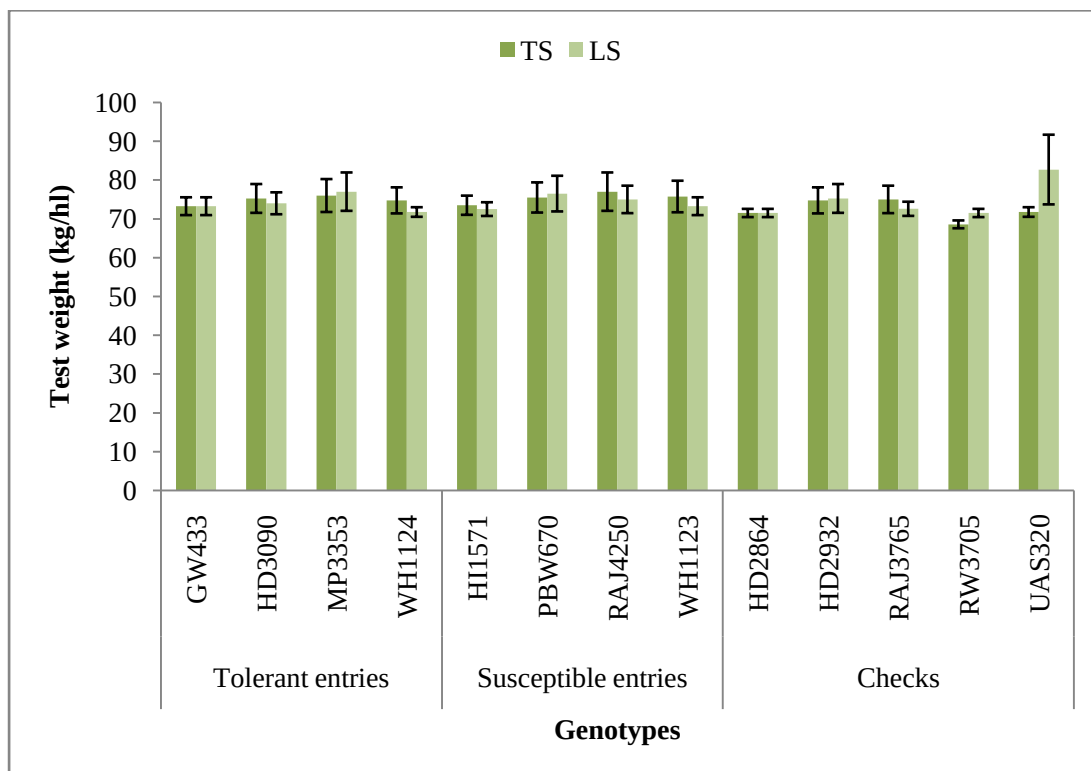


Fig 20a: Test weight of grains in wheat genotypes under timely and late sown conditions in MLHT I

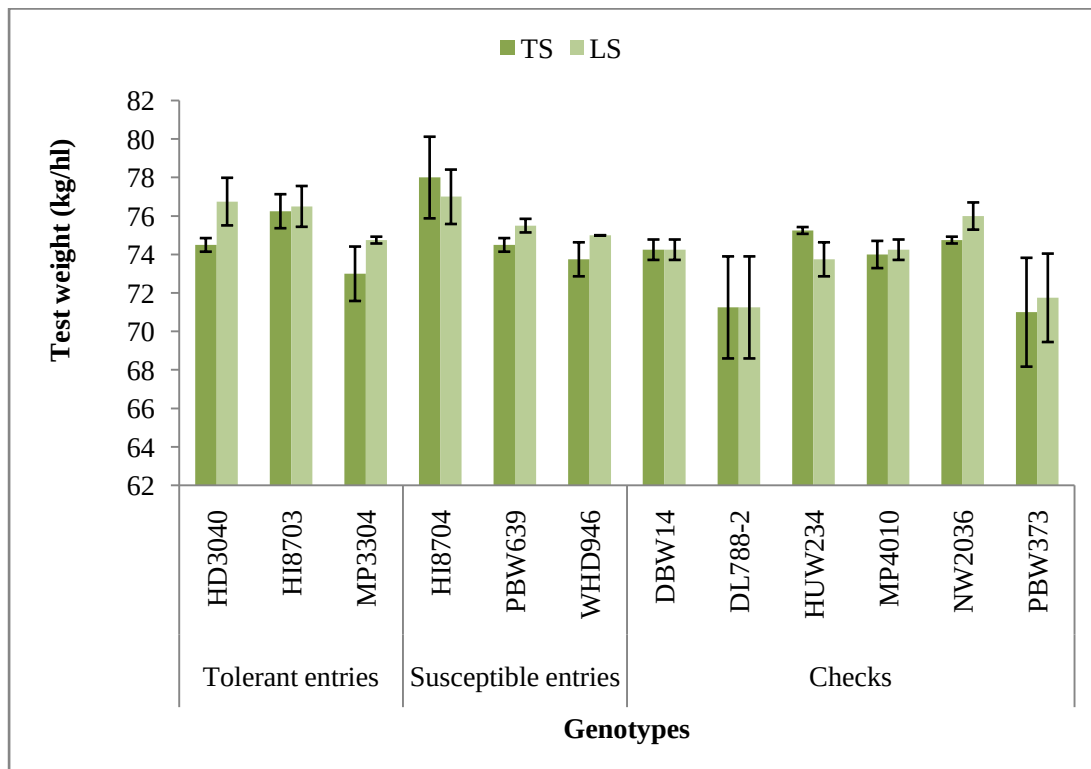


Fig 20b: Test weight of grains in wheat genotypes under timely and late sown conditions in MLHT II

4.3.3 Grain Hardness

In trial MLHT-I (Fig 21a), the kernel hardness ranged (Table 13a) from 6.97 to 11.01kg under timely sown conditions and 6.40 to 10.56 kg under late sown conditions with mean value of 9.46 and 8.41kg for timely and late sown conditions, respectively.

Under timely sown conditions, check variety HD 2864 found to be the best variety with value of 11.01. The tolerant entry GW 433, susceptible entry WH 1123, checks HD 2864 and RW 3705 also found to be good varieties. Among late sown conditions, the GW 433 tolerant entry was found to be best variety with value of 10.56 HD 3090, MP 3353 tolerant entries were also good. GW 433 and HD 3090 showed stable grain hardness in two different environments hence proved to be tolerant to high temperature stress.

In MLHT-II trial (Fig 21b), the kernel hardness (Table 13b) ranged from 6.61to 9.10 kg under timely sown conditions and 6.38 to 8.81 kg under late sown conditions with mean values of 7.80 and 7.61 kg for timely and late sown condition, respectively. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II. Overall MLHT II trial entries had comparatively lower grain hardness as compared to MLHT I entries and grain hardness mean values were found to be lower under late sown conditions in both trials MLHT I and MLHT II. This indicates that environmental conditions (high temperature during late sown conditions) affect hardness of wheat grains. The grain hardness showed is in a range of 9 to 11 kg to produce good quality chapattis, therefore the most of the entries of MLHT I trial were fall in this desirable range and can produce chapattis of acceptable quality.

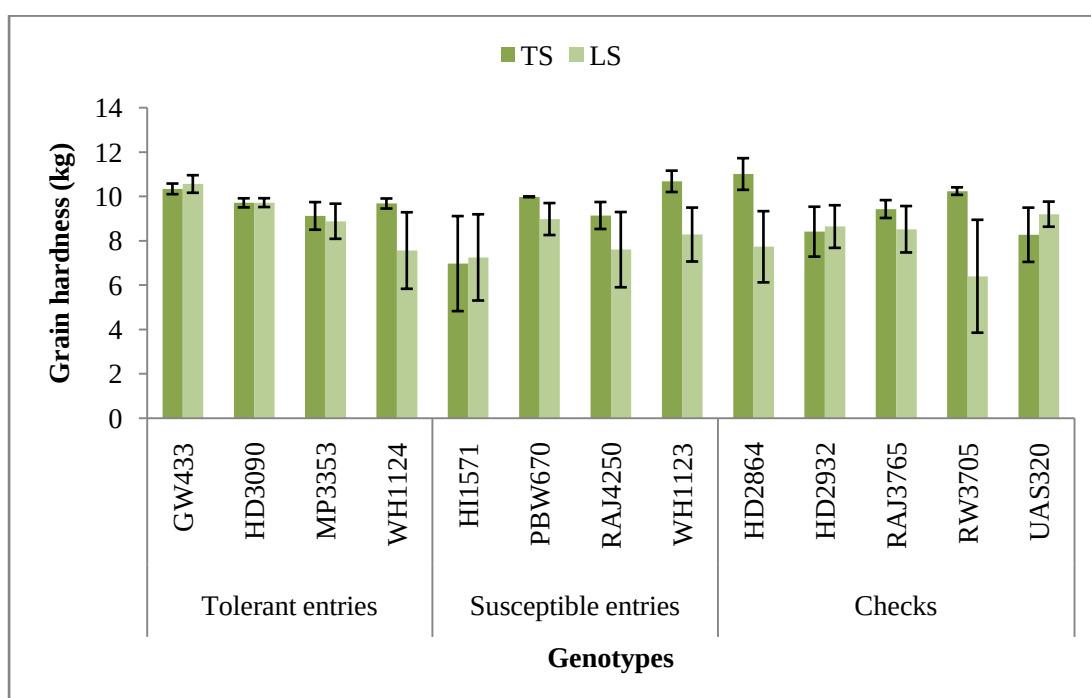


Fig 21a: Hardness of grains in wheat genotypes under timely and late sown conditions in MLHT I

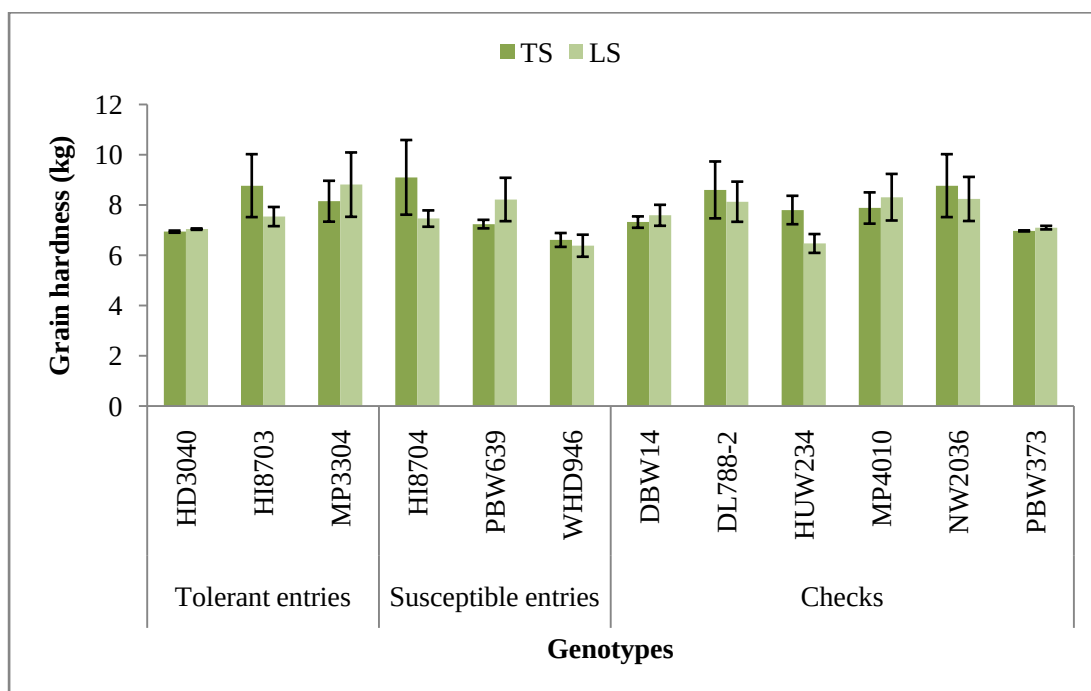


Fig 21b: Hardness of grains in wheat genotypes under timely and late sown conditions in MLHT II

Tashiro and Wardlaw (1990) observed that many kernel characteristics that affect the end use quality were altered at $> 30-35^{\circ}\text{C}$. They also reported that high temperatures caused shrinking, notching, splitting and chalking of kernels. So, it implies that kernel hardness get affected by heat stress.

4.3.4 Protein content

In MLHT-I, the protein content (Table 15 a) ranged from 9.49 to 11.65 percent under timely sown conditions and 10.03 to 12.98 percent under late sown conditions with mean values of 10.5 percent for timely sown and 11.1 percent for late sown conditions. So, the effect of sowing had found to be significant ($p < 0.05$). Under timely sown conditions tolerant entry MP 3353 had found to be the best entry with a value of 11.6 percent.

The susceptible entries PBW 670 with protein content of 11.4 percent and also RAJ 4250 with 10.98 percent were found to be good varieties. Tolerant entry MP 3353 also among late sown conditions was found to be best entry having value of 12.9 percent. Other tolerant entry WH 1124, susceptible entry PBW 670 and check HD 2932 were good varieties having values of 12.2, 11.1 and 11.7 percent, respectively.

It implies that under late sown conditions had higher protein content was observed due to shriveling of grains under heat stress.

In MLHT-II, the protein content (Table 15b) ranged from 8.92 to 11.08 percent under timely sown and 9.84 to 11.55 percent under late sown conditions with mean value of 10.0 and 10.8 percent for timely and late sown conditions, respectively.

Table 14a: Chemical characteristics of grains in wheat genotypes under timely and late sown condition in MLHT I

Genotypes		Protein content (%)		SDS-Sedimentation value (cc)		Phenol reaction score	
		TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	10.5±0.35	10.7±0.49	39±0.71	41±0.71	3.9±0.64	3.4±0.28
	HD3090	10.4±0.28	10.9±0.64	38±0.41	40±0.00	2.8±0.14	2.8±0.14
	MP3353	11.6±1.13	12.9±2.05	44±2.83	49±6.36	3.9±0.64	3.5±0.35
	WH1124	10.6±0.42	12.2±1.56	50±7.07	59±13.44	3.6±0.42	3.2±0.14
Susceptible Entries	HI1571	10.2±0.14	10.2±0.14	47±4.95	50±7.07	3.0±0.00	2.9±0.07
	PBW670	11.4±0.99	11.1±0.78	51±7.78	54±9.90	4.0±0.71	3.45±0.32
	RAJ4250	10.9±0.64	10.9±0.64	44±2.83	50±7.07	2.8±0.14	3.15±0.11
	WH1123	10.1±0.07	10.9±0.64	44±2.83	50±7.07	3.1±0.07	3.15±0.11
Checks	HD2864	10.2±0.14	10.2±0.14	37±2.12	43±2.12	3.3±0.21	2.7±0.21
	HD2932	9.4±0.42	11.7±1.20	31±6.36	50±7.07	2.5±0.35	2.4±0.42
	RAJ3765	10.7±0.49	10.0±0.00	42±1.41	36±2.83	2.9±0.07	2.8±0.14
	RW3705	10.6±0.42	10.8±0.57	46±4.24	43±2.12	3.8±0.57	3.6±0.42
	UAS320	10.6±0.42	11.0±0.71	40±0.00	45±3.54	2.9±0.07	2.9±0.07
Range		9.49-11.65	10.03-12.98	31-51	40-59	2.5-4.0	2.4-3.6
Mean		10.5	11.1	42	47	3.2	3.1
CD at 5% Treatments		TS=0.42,LS=0.66		TS=3.23,LS=2.33		TS=0.22,LS=0.11	

Values are mean ± SD of three replicates.

Table 14b: Chemical characteristics of grains in wheat genotypes under timely and late sown condition in MLHT II

Genotypes		Protein content (%)		SDS-Sedimentation value (cc)		Phenol reaction score	
		TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	9.8±0.57	11.1±1.48	43±2.12	55±10.61	3.2±0.71	3.5±0.92
	HI8703	8.9±0.07	9.8±0.57	38±1.41	39±0.71	1±0.85	1.2±0.71
	MP3304	10.1±0.78	11.5±1.77	45±3.54	50±7.07	3.2±0.71	3.6±0.99
Susceptible Entries	HI8704	9.5±0.35	10.1±0.78	41±0.71	38±1.41	1.4±0.57	1.1±0.78
	PBW639	10±0.71	11.4±1.70	42±1.41	47±4.95	3.9±1.20	3.8±1.13
	WHD946	9.4±0.28	10.5±1.06	29±7.78	34±4.24	1±0.85	1±0.85
Checks	DBW14	10.7±1.20	10.5±1.06	43±2.12	50±7.07	3.8±1.13	3.8±1.13
	DL788-2	11±1.41	10.4±0.99	45±3.54	38±1.41	3.1±0.64	3.5±0.92
	HUW234	9.2±0.14	10.3±0.92	41±0.71	44±2.83	3.4±0.85	3.7±1.06
	MP4010	10.4±0.99	11.4±1.70	41±0.71	48±5.66	3.4±0.85	3.4±0.85
	NW2036	10.6±1.13	11.4±1.70	43±2.12	44±2.83	2.4±0.14	2.4±0.14
	PBW373	10.8±1.27	10.7±1.20	44±2.83	48±5.66	3.8±1.13	3.8±1.13
Range		8.92-11.08	9.84-11.55	29- 45.5	34.5- 55	1-3.9	1-3.8
Mean		10	10.8	41.2	44.6	2.8	2.9
CD at 5% Treatments		TS=0.34,LS=0.31		TS=1.48,LS=3.08		TS=0.17,LS=0.87	

Values are mean ± SD of three replicates.

Under timely sown conditions (Fig 22a, b), the check DL 788-2 was the best variety with 11.01 percent protein content. Other checks NW 2036, PBW 373 and DBW 14 were good varieties. Under late sown conditions, tolerant entry MP 3304 was found to be best entry with 11.5 percent protein, entries PBW 639, checks MP 4010 and NW 2036 were good varieties having 11.4 percent. The mean value of protein content was observed higher under late sown conditions in both trials MLHT I and MLHT II.

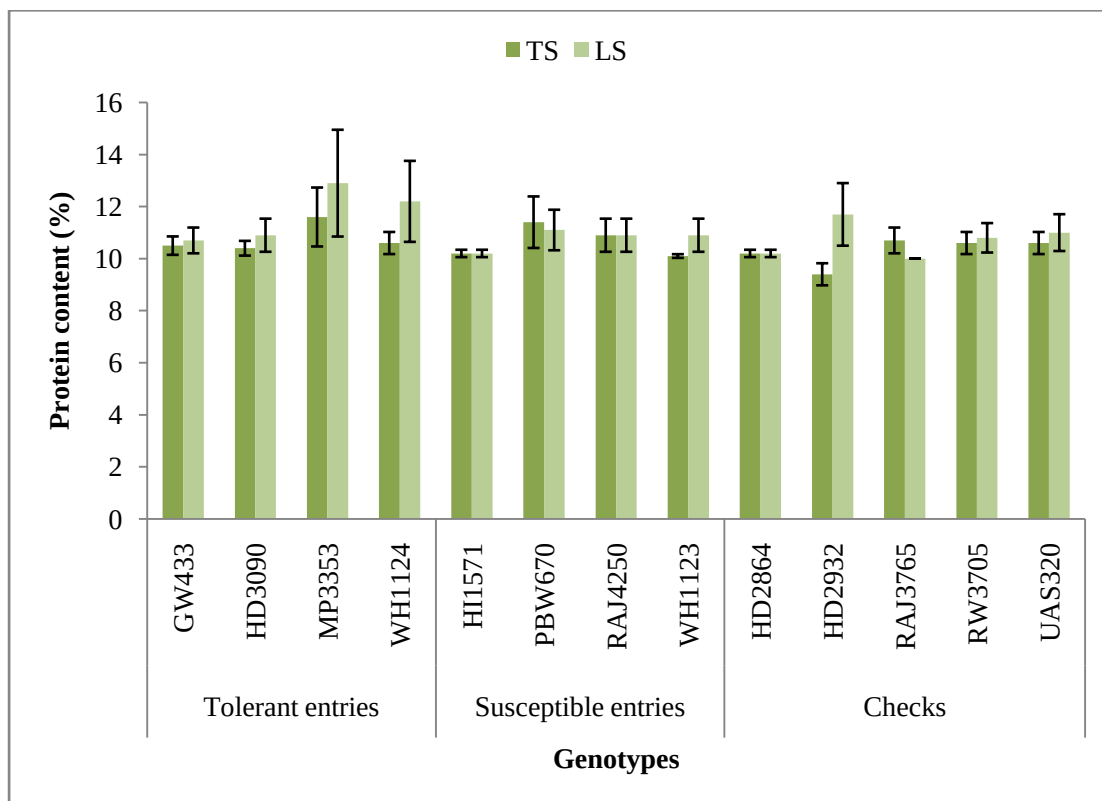


Fig 22a: Protein content of grains in wheat genotypes under timely and late sown conditions in MLHT I

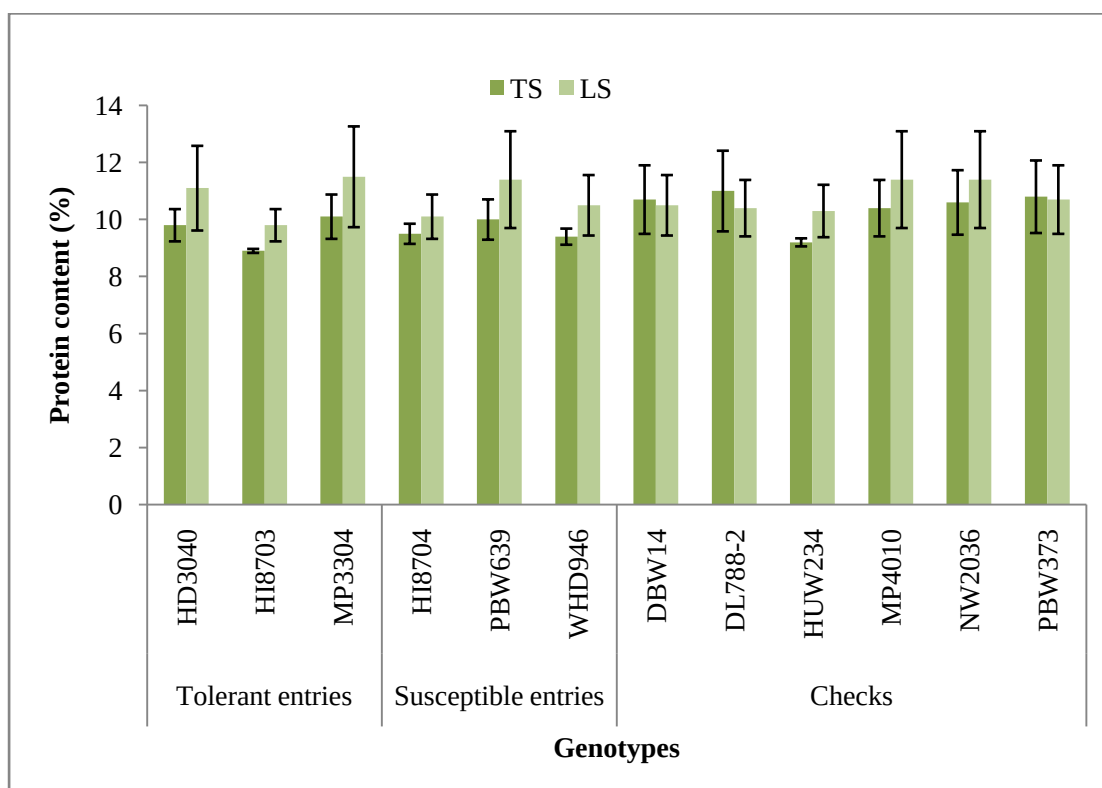


Fig 22b: Protein content of grains in wheat genotypes under timely and late sown conditions in MLHT II

It implies that sowing effect was found to be significant. Reynolds *et al* (2001) reported that protein percent was significantly higher in late sown wheat grains as compared to timely sown, as heat shock proteins are synthesized at very high rates under high temperature stress. Under heat stress, the protein content tends to increase significantly in wheat genotypes (Correll *et al* 1994; Wardlaw *et al* 1989; Guedira *et al* 2002; Dias *et al* 2009a). Similarly observations have been reported recently by Castro *et al* (2007) who observed an increase in grain protein content with heat stress.

4.3.5 SDS - Sedimentation Value

In MLHT-I, the SDS-sedimentation value (Table 15a) ranged from 31 to 51 cc under timely sown and 41 to 59 cc under late sown conditions with mean value of 42 and 47 cc, respectively. WH 1124, having a sedimentation value of 50 cc under timely sown conditions and 59 cc under late sown conditions, reflected to be a tolerant variety. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

Under late sown conditions, HI 1571, RAJ 4250, WH 1123 and check HD 2932 were the varieties having a sedimentation value of 50 cc. The sowing effect was found to be significant. The higher mean and range values under late sown conditions indicated lesser damage to the functional quality of proteins due to heat stress to which those entries were subjected. The entries having a value of 35 cc to 50 cc are preferred for chapatti making whereas ones with higher values are better for bread making.

In MLHT-II, the sedimentation value (Table 15b) ranged from 29 to 45 cc under timely sown and 34 to 55 cc under late sown conditions with a mean value of 41 and 44 cc for timely and late sown conditions, respectively. The check DL 788-2 was found to be the best variety with value of 45 cc under timely sown conditions. The tolerant entry HD 3040 having increased sedimentation value of 55 cc was found to be best entry under late sown conditions. Among the late sown (Fig 23a, b), the tolerant entry MP 3304 and check DBW 14 were having a sedimentation value of 50 cc.

The loss of functional quality has already been reported by Uhlen *et al* (1998) under heat stress. Singh *et al* (2000) studied the sedimentation value of newly released wheat varieties and reported a range of 34 cc to 44 cc with a mean value of 40 cc. The entries MP 3353 and WH 1124 from MLHT I and HD 3040 and MP 3304 from MLHT II were better in tolerance to heat stress.

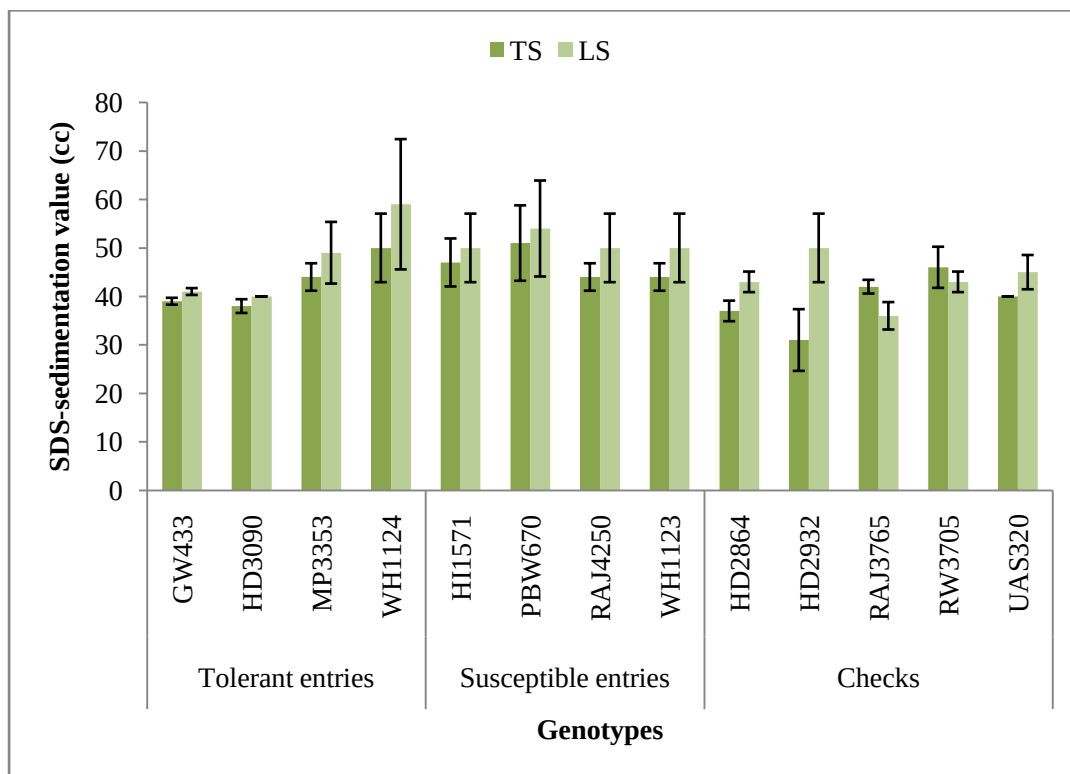


Fig 23a: SDS-Sedimentation value of grains in wheat genotypes under timely and late sown conditions in MLHT I

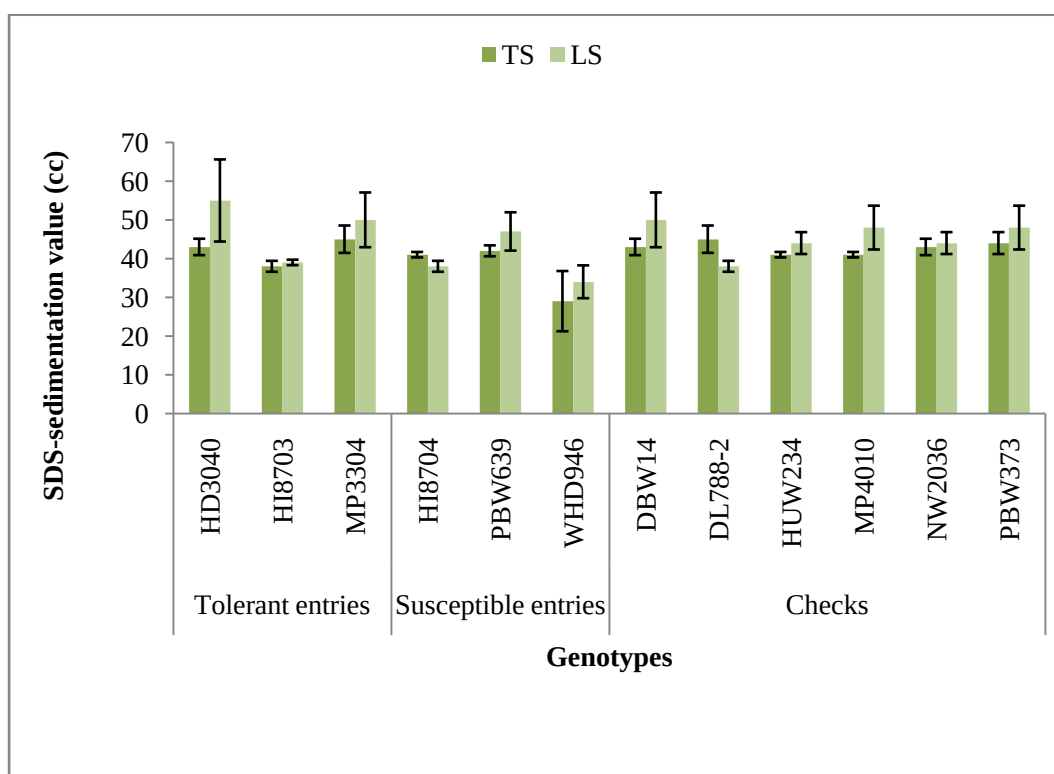


Fig 23b: SDS-Sedimentation value of grains in wheat genotypes under timely and late sown conditions in MLHT II

4.3.6 Phenol Reaction Test

In MLHT-I (Fig 24a), phenol reaction score (Table 15a) ranged from 2.5 to 4.0 under timely sown conditions and 2.4 to 3.6 under late sown conditions with mean values of 3.2 and 3.1, respectively. The phenol reaction score of HD 3090 was found to be lower among the selected tolerant entries under timely and late sown conditions. The check HD 2932 having value of 2.5 and 2.4 (lowest) found to be the best check under both conditions. It was found to be significant ($p < 0.05$) in both the trials MLHT I and MLHT II.

In MLHT-II (Fig 24b), phenol reaction score (Table 15b) ranged from 1.0 to 3.9 under timely sown and 1.0 to 3.8 under late sown conditions with mean values of 2.8 and 2.9, respectively. The entry HI 8703 and entries WHD 946 and HI 8704 had lower phenol reaction score considered to be good varieties under both timely and late sown conditions. The lower PRS value was indicative that the dough can be stored for longer time. Majority of entries were showing phenol reaction score of less than 4.0 that is in desirable range for chapatti making. Results are significant ($p < 0.05$) in both trials MLHT I and MLHT II.

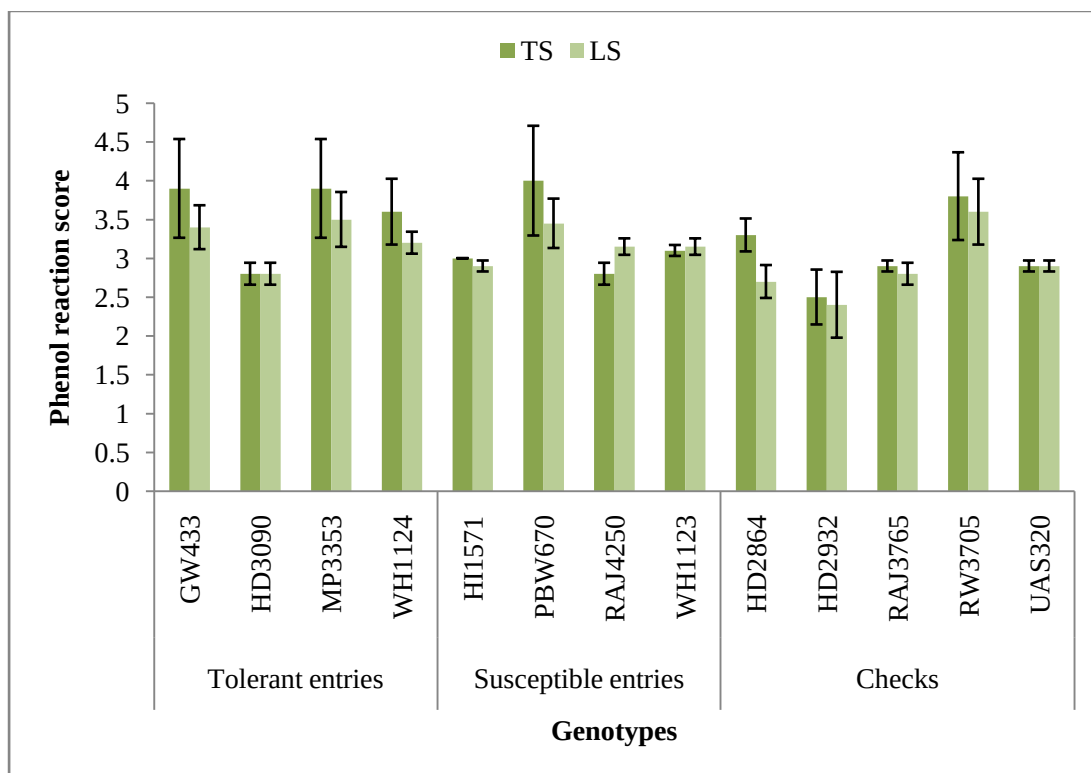


Fig 24a: Phenol reaction score of grains in wheat genotypes under timely and late sown conditions in MLHT I

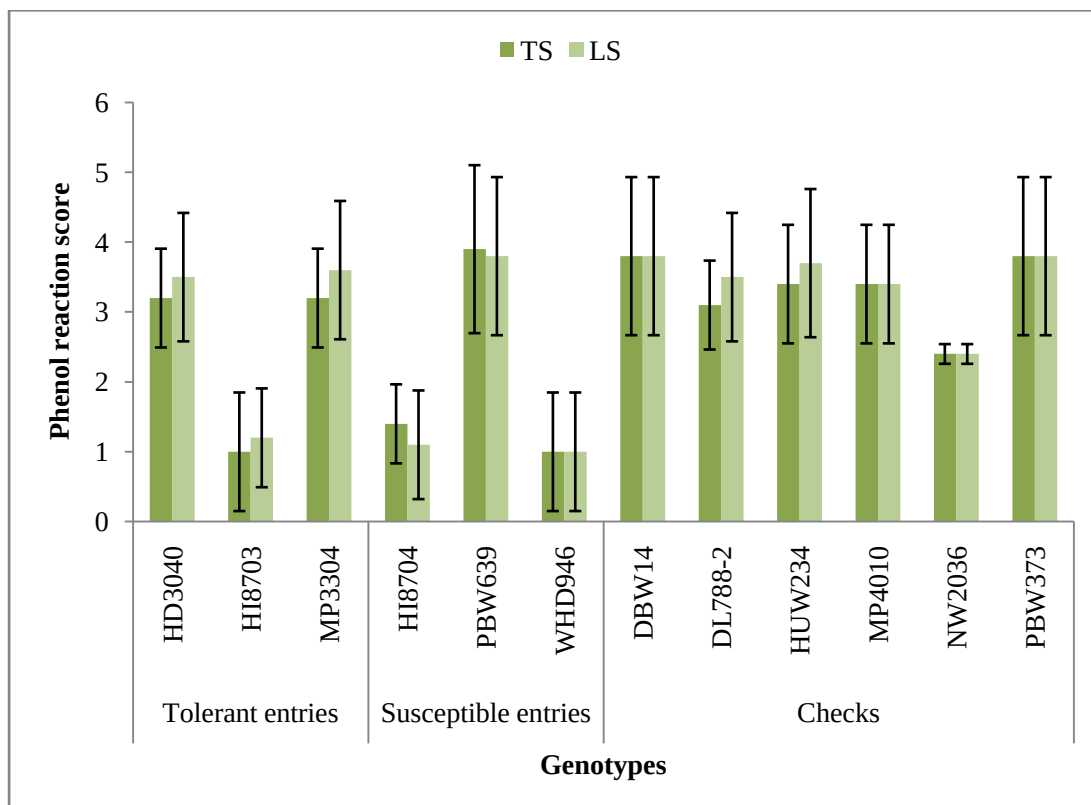


Fig 24b: Phenol reaction score of grains in wheat genotypes under timely and late sown conditions in MLHT I

4.3.7 Grain Plumpness

In MLHT-I the fraction of 2.8 mm grains (Table 16a) ranged from 3.77 to 67.2 g under timely sown conditions and 3.13 to 74.58 g under late sown conditions with mean values of 30.42 and 21.09 g, respectively. Tolerant entries MP 3353 had higher kernel size of 2.8 mm under both timely and late sown conditions with means values of 67.2 and 74.58 g. For 2.5 mm fraction it ranged from 26.84 to 53.44 g under timely sown and 22.68 to 54.39 g under late sown conditions with mean values of 43.16 and 43.87 g, respectively. For fraction of 2.2 mm, it ranged from 4.89 to 42.46 g under timely sown and 2.4 to 48.7 g under late sown conditions with mean values of 20.39 and 26.02 g, respectively. The fourth fraction of plup kernels had a range from 1.14 to 21.93 g under timely sown and 0.74 to 22.1 g under late sown conditions with mean values of 6.1 and 8.6 g, respectively. For fraction of 2.5 mm, the susceptible entry WH1123 had highest value of 53.44 g under timely sown conditions and check UAS 320 had highest value under late sown conditions with mean value of 54.39 g. For 2.2 mm and plup kernels the susceptible entry HI 1571 had highest values under both timely and late sown conditions.

It implies that entry MP 3353 has more grains of fraction size 2.8 mm yields more flour content, reflects the tolerance behavior of MP 3353.

Table 15a: Plumpness of grains in wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		2.8mm (g)		2.5mm (g)		2.2mm (g)		Plup kernels (g)	
		TS	LS	TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	25.17±3.66	22.91±2.06	47.32±5.18	49.99±7.06	22.06±1.46	21.49±1.05	5.52±0.37	5.68±0.49
	HD3090	32.68±8.97	13.67±4.48	52.14±6.45	51.12±7.86	13.32±4.72	23.18±2.25	1.99±0.13	3.99±0.71
	MP3353	67.20±8.02	74.58±9.90	26.84±6.58	22.68±6.23	4.89±2.04	2.46±0.33	1.14±0.73	0.74±0.01
	WH1124	34.91±9.54	8.94±7.82	46.34±9.31	47.19±5.08	15.02±3.52	32.79±9.04	3.83±0.83	11.33±4.48
Susceptible entries	HI1571	3.77±5.48	3.13±1.93	31.69±4.48	26.28±9.70	42.46±5.88	48.7±2.29	21.93±1.97	22.1±1.09
	PBW670	45.67±1.41	23.53±2.50	39.31±5.88	44.86±3.44	12.86±5.05	24.11±2.91	2.31±1.90	7.47±1.75
	RAJ4250	24.13±2.92	6.24±9.73	48.89±1.49	42.46±1.74	22.58±1.82	38.86±3.34	4.59±0.29	13±3.66
	WH1123	18.09±1.35	12.55±5.27	53.44±6.29	47.28±5.15	24.32±3.05	32.92±3.14	4.44±0.40	7.5±1.77
Checks	HD2864	30.00±7.07	30.08±7.13	42.61±9.50	43.24±2.29	17.83±1.53	24.76±3.37	9.67±3.30	9.86±3.44
	HD2932	45.86±3.54	18.28±1.22	41.03±1.85	50.98±7.76	10.59±1.65	24.76±3.37	2.54±1.74	6.24±0.88
	RAJ3765	12.75±5.13	11.84±5.77	46.49±1.73	48.02±5.67	32.66±3.95	28.7±2.15	7.94±2.08	8.12±2.21
	RW3705	11.44±6.05	27.73±5.47	48.34±4.59	41.82±1.29	32.00±3.49	19.59±0.29	8.17±2.24	11.06±4.29
	UAS320	43.76±2.12	20.67±0.47	36.62±2.39	54.39±7.18	14.49±3.90	20.49±0.35	5.23±0.16	4.62±0.27
Range		3.77-67.2	3.13-74.58	26.84-53.44	22.68-54.39	4.89-42.46	2.46-48.7	1.14-21.93	0.74-22.1
Mean		30.42	21.09	43.16	43.87	20.39	26.02	6.1	8.6
CD at 5% Treatments		TS=17.93, LS=2.38		TS=3.70, LS=2.92		TS=2.21, LS=5.43		TS=10.07, LS=NS	

Values are mean ± SD of three replicates.

Table 15b: Plumpness of grains in wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		2.8mm (g)		2.5mm (g)		2.2mm (g)		Plup kernels (g)	
		TS	LS	TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	35.09±3.47	12.24±1.63	50.62±3.97	50.14±3.63	11.2±0.57	29.52±1.39	2.49±0.48	8.30±1.63
	HI8703	57.99±2.72	60.44±4.45	28.23±1.86	25.80±1.58	10.67±0.94	10.61±0.98	3.30±0.91	3.27±0.93
	MP3304	19.77±4.30	8.04±2.60	49.07±2.88	42.86±1.51	24.19±2.62	38.25±1.56	7.24±0.88	11.21±1.68
Susceptible entries	HI8704	72.68±3.11	62.84±3.15	20.66±1.21	23.16±1.44	5.82±1.37	10.5±1.06	1.22±0.38	3.20±0.98
	PBW639	22.78±2.18	30.64±2.62	51.34±4.48	48.79±2.68	22.05±2.11	19.88±1.57	4.04±0.39	5.90±1.07
	WHD946	63.93±3.92	63.64±3.72	21.52±1.60	24.61±1.42	9.26±1.94	9.07±2107	4.98±0.72	2.68±0.35
Checks	DBW14	14.10±1.31	10.36±2.96	48.44±2.43	48.1±2.19	30.1±2.80	31.02±1.45	7.40±0.99	10.33±1.06
	DL788-2	25.41±1.32	18.63±1.11	41.22±2.67	42.94±1.46	23.04±2.81	23.00±1.78	10.32±1.05	11.5±1.89
	HUW234	24.7±1.82	13.42±1.79	41.35±2.58	43.25±1.24	25.11±2.27	23.82±1.36	9.15±1.23	10.59±1.25
	MP4010	19.49±1.50	13.42±1.79	56.48±2.12	54.22±2.52	19.97±1.64	19.05±1.99	3.9±1.48	5.42±0.41
	NW2036	17.75±1.73	17.93±1.61	52.7±4.44	45.8±0.57	25.14±2.29	23±1.78	4.85±0.81	4.79±0.86
	PBW373	38.51±1.05	25.52±1.24	40.07±3.49	41.26±2.64	16.54±3.21	31.49±1.78	5.11±0.63	9.52±1.49
Range		14.10-72.68	8.04-63.64	20.66-56.48	23.16-54.22	5.82-30.1	9.07-38.25	1.22-10.32	2.68-11.5
Mean		34.35	28.95	41.81	40.91	18.59	23.15	5.33	7.23
CD at 5% Treatments		TS=2.16, LS=12.9		TS=2.75, LS=3.23		TS=2.42, LS=3.24		TS=1.26, LS=1.15	

Values are mean ± SD of three replicates.

In MLHT-II, the grain fraction of 2.8 mm size (Table 16b) ranged from 14.1 to 72.68 g under timely sown and 8.40 to 63.64 g under late sown conditions with mean values of 34.35 and 28.95 g, respectively. The fraction of 2.5 mm size, it ranged from 20.66 to 56.48 g under timely sown and 23.16 to 54.22 g under late sown conditions with mean values of 41.81 and 40.91g, respectively. For 2.2 mm, the grain fraction ranged from 5.82 to 30.1 g under timely sown and 9.07 to 38.25 g under late sown conditions with mean values of 18.59 and 23.15 g, respectively. For plup kernels, it ranged from 1.22 to 10.32 g under timely sown conditions and 2.68 g to 11.50 g under late sown conditions with mean value of 5.33 and 7.23g.

Among timely sown conditions, entry HI 8704 had highest 2.8 mm sized fraction and WHD 946 had highest value under late sown conditions. For 2.5 mm, check variety MP 4010 had highest values for both timely and late sown conditions. For 2.2 mm, tolerant entry MP 3304 had highest value of 38.25 g under late sown conditions. For plup kernels check DL 788-2 had highest value under both the timely and late sown conditions. The entry HI 8703 had largest fraction of 2.8 mm sized grains among the tolerant entries and fraction was found to be increased under late sown conditions confirms tolerance of this entry to high temperature stress.

For 2.8 mm (fig 25a-h) the HI 8704 and WHD 946 had higher value so can yield more flour content, but fraction of 2.8 mm sized grains was decreased under late sown conditions that suggested the susceptible nature of these entries against high temperature stress. It was found to be non significant ($p < 0.05$) in trial MLHT I and significant in MLHT II.

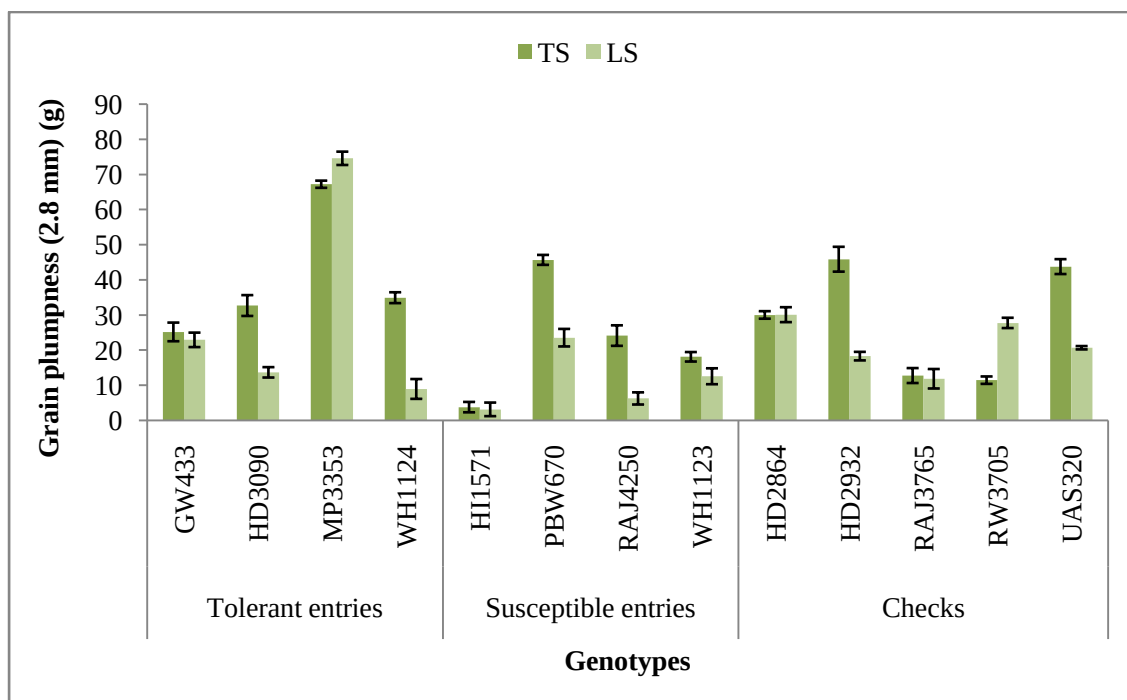


Fig 25a: Plumpness of grains (2.8 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT I

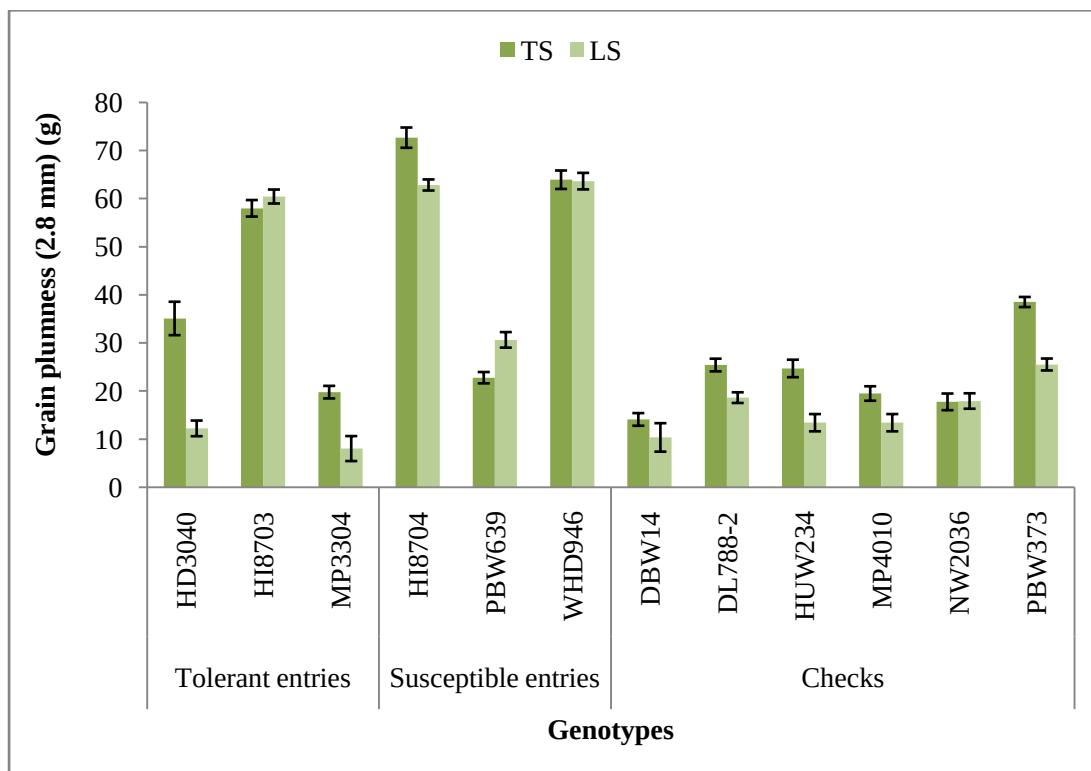


Fig 25b: Plumpness of grains (2.8 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT II

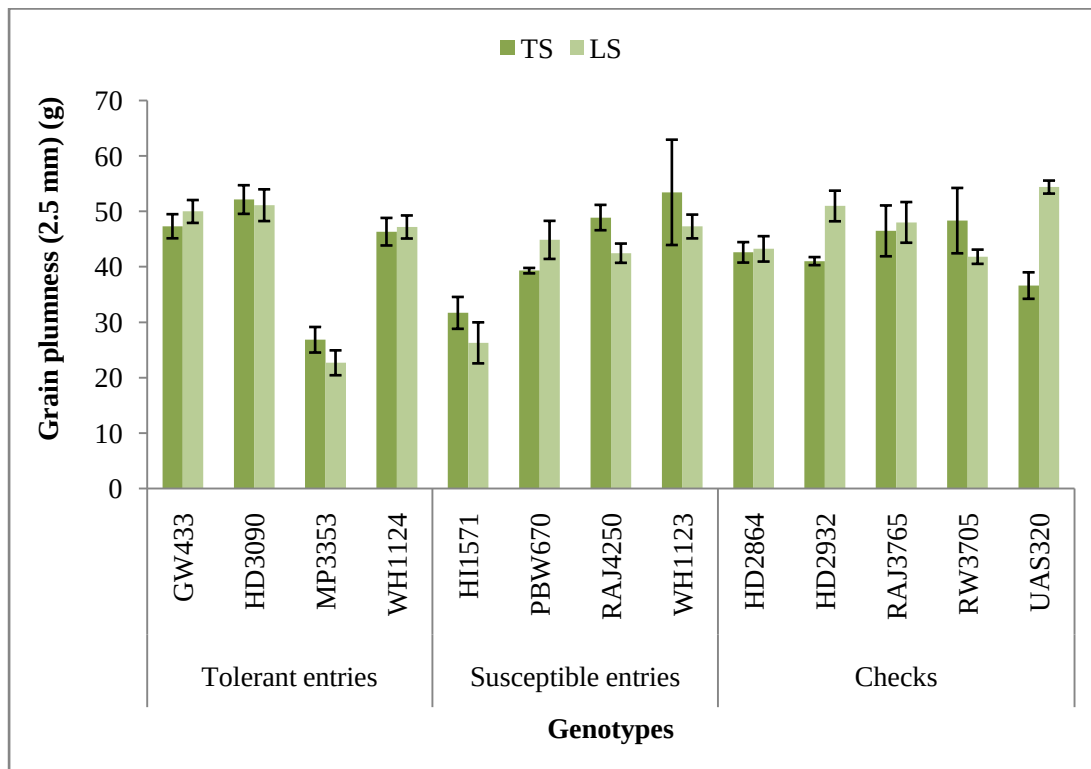


Fig 25c: Plumpness of grains (2.5 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT I

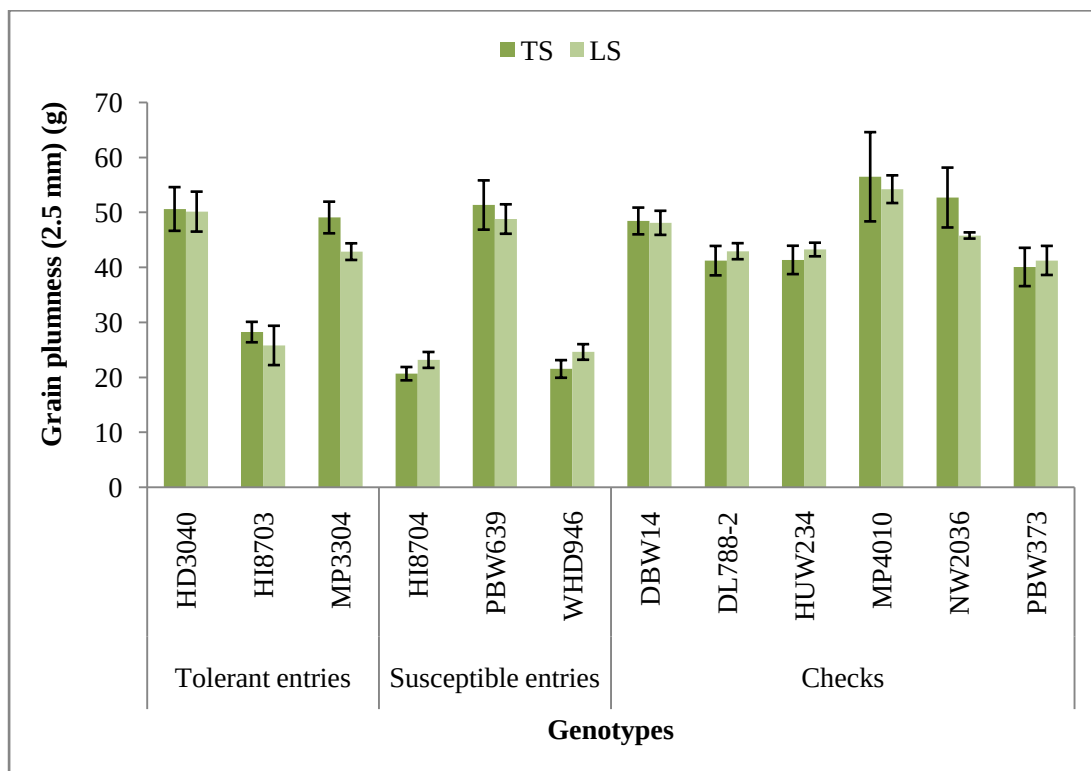


Fig. 25d: Plumpness of grains (2.5 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT II

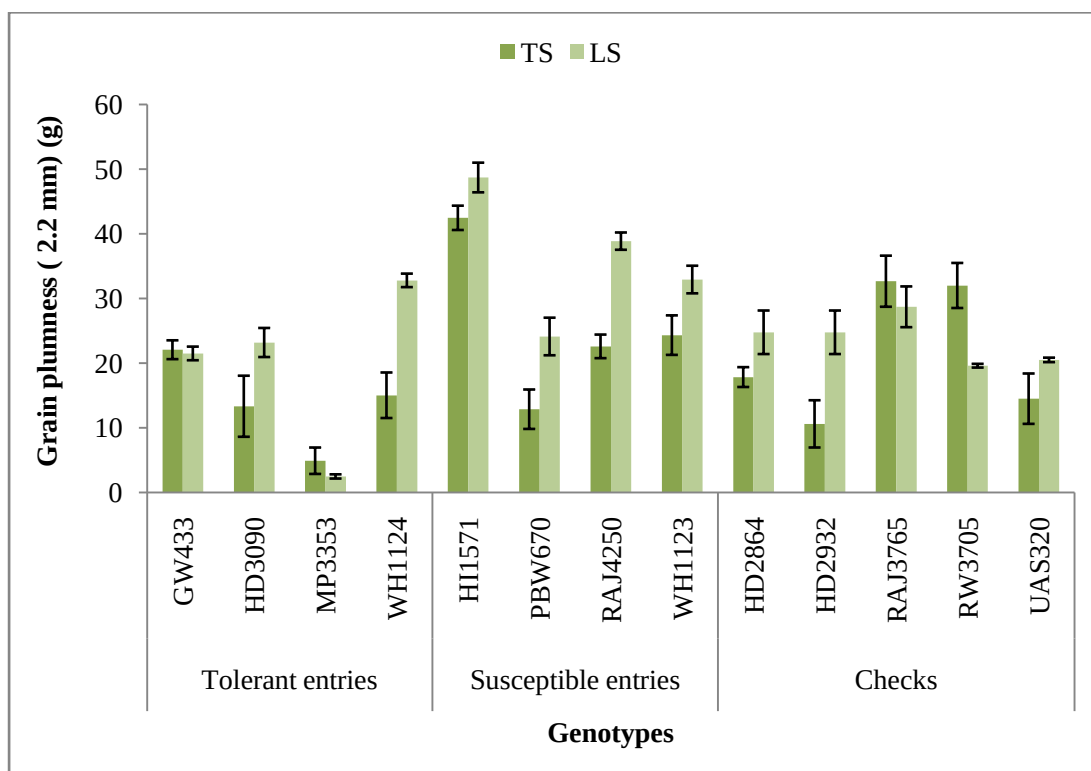


Fig 25e: Plumpness of grains (2.2 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT I

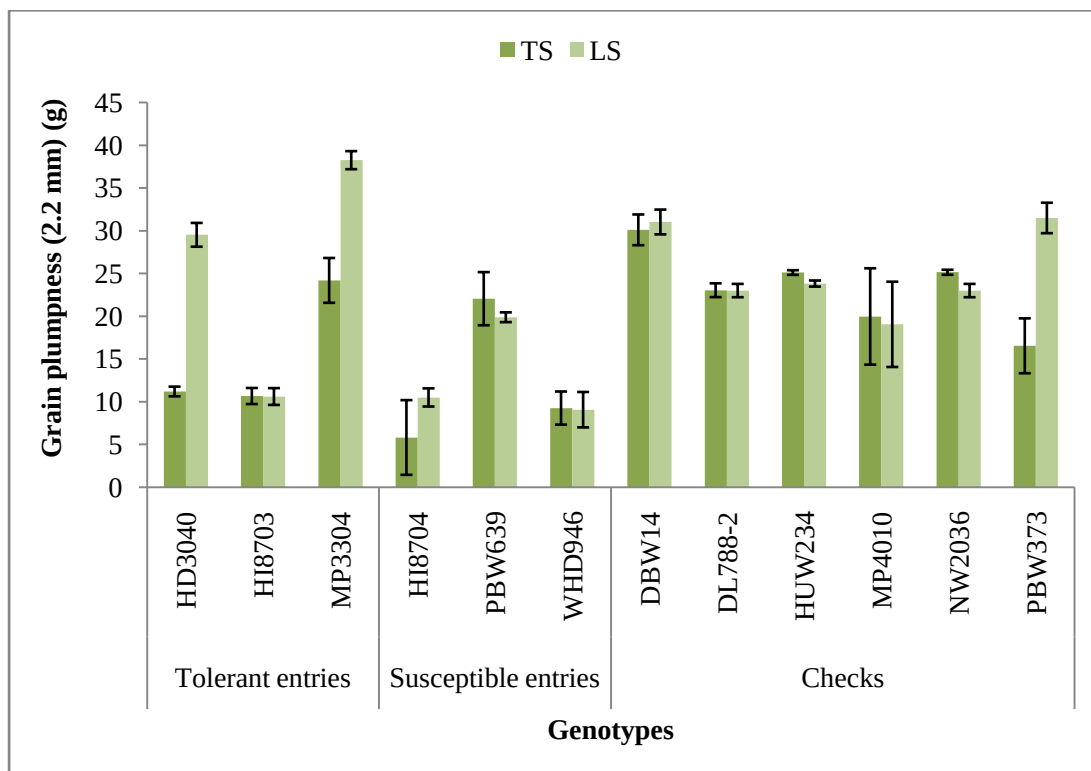


Fig 25f: Plumpness of grains (2.2 mm sized fraction) in wheat genotypes under timely and late sown conditions in MLHT II

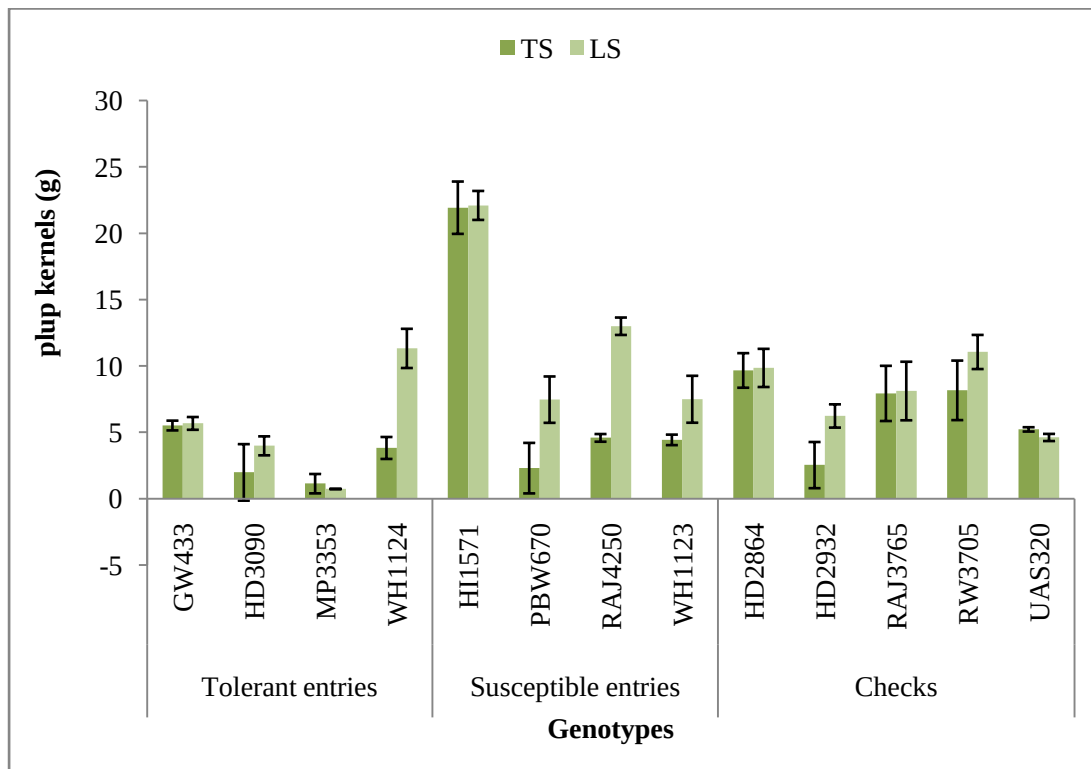


Fig 25g: Plumpness of grains (plup kernels) in wheat genotypes under timely and late sown conditions in MLHT I

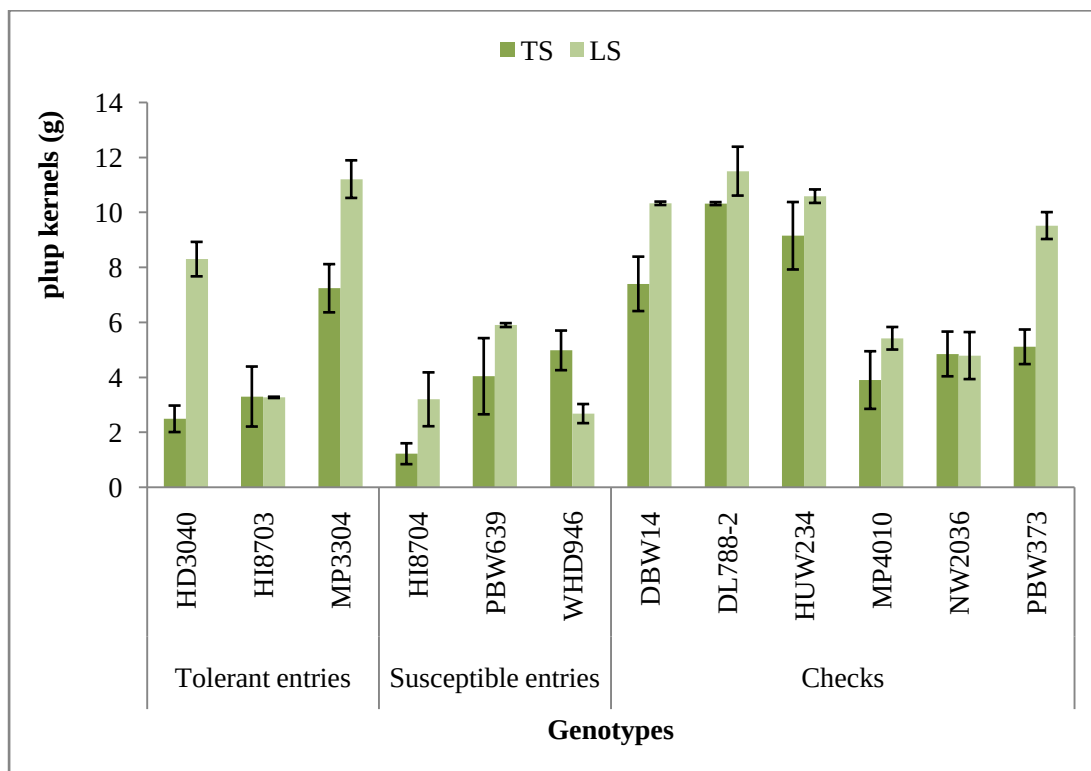


Fig 25h: Plumpness of grains (plup kernels) in wheat genotypes under timely and late sown conditions in MLHT II

4.3.8 Gluten Content and Index

Gluten content and gluten index depicted in Table 17a and Table 17 b had found to be significant in both trials MLHT I and MLHT II.

4.3.8.1 Dry Gluten

In MLHT-I (Fig 26a), dry gluten content ranged from 7.0 to 10.6 percent under timely sown and 9.6 to 10.9 percent under late sown conditions with mean values of 9.3 and 10.2 percent. All the genotypes under late sown conditions showed higher dry gluten content. The tolerant entry HD 3090, MP 3353 and WH 1124 and check varieties HD 2864 and UAS 320 had high dry gluten content under late sown conditions.

In MLHT-II (Fig 26b), it ranged from 8.2 to 10.5 percent under timely sown conditions and 9.8 to 10.9 percent under late sown conditions with mean values of 9.5 and 10.4 percent, respectively. All the genotypes showed increased dry gluten content under late sown conditions. The tolerant entry HI 8703 and MP 3304 had highest dry gluten content of values 10.9 and 10.6 percent under late sown conditions. The check varieties NW 2036 and PBW 373 were also found to be good varieties under late sown conditions. So the dry gluten content was found to be significant ($p < 0.05$) under heat stress in both the trials MLHT I and MLHT II.

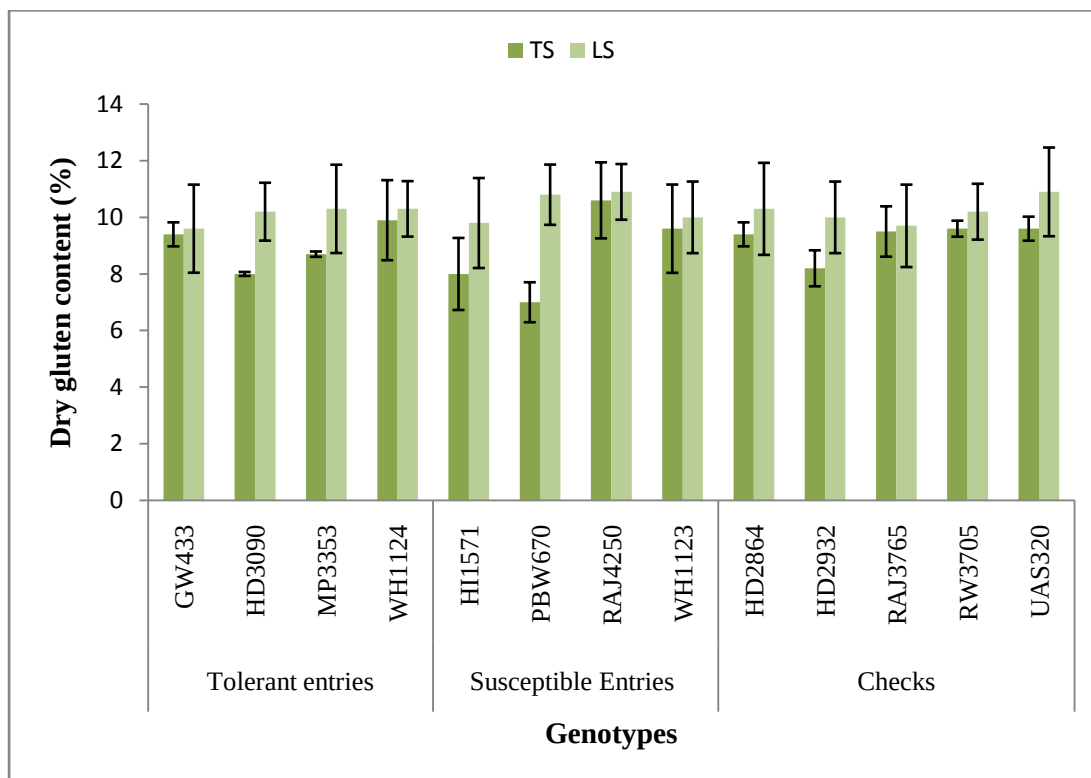


Fig 26a: Content of dry gluten in wheat genotypes under timely and late sown conditions in MLHT I

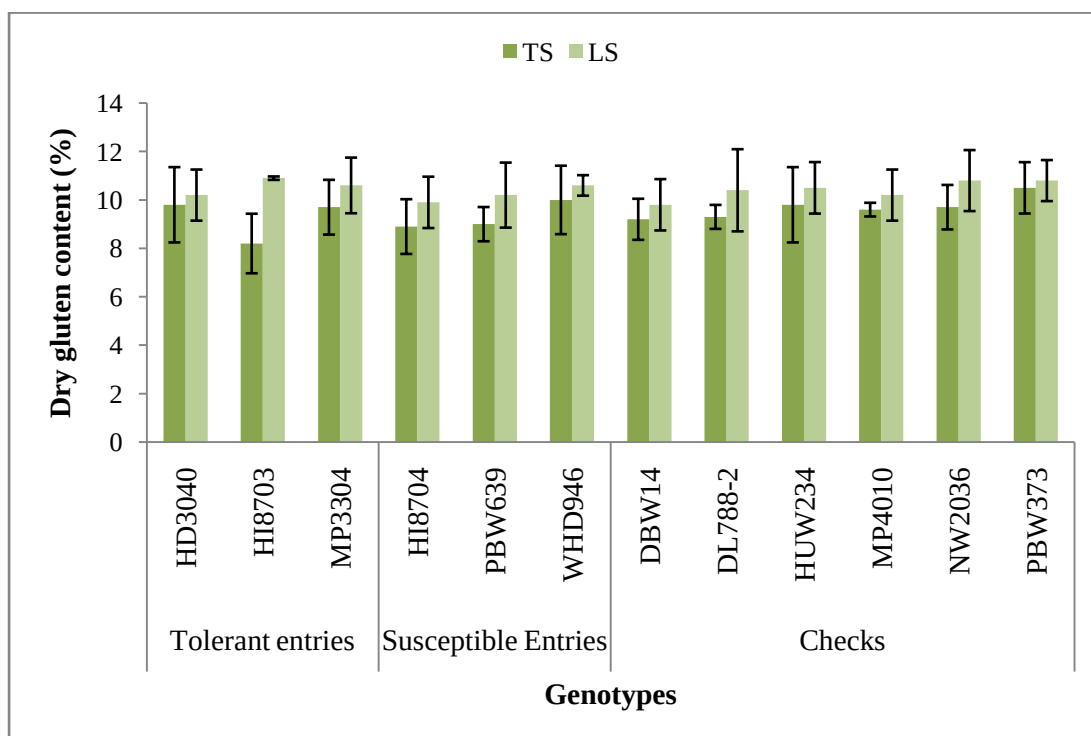


Fig 26b: Content of dry gluten in wheat genotypes under timely and late sown conditions in MLHT II

4.3.8.2 Wet Gluten

In MLHT-I (Fig 26c), the wet gluten ranged from 21.0 to 31.6 percent under timely sown conditions with mean value of 24.5 percent and it ranged from 20.5 to 30.4 percent under late sown conditions with mean value of 24.9 percent, respectively. The tolerant entry WH 1124 had highest wet gluten under late sown conditions had value of 30.4 percent. The check HD 2932 was also found to be good variety under late sown conditions.

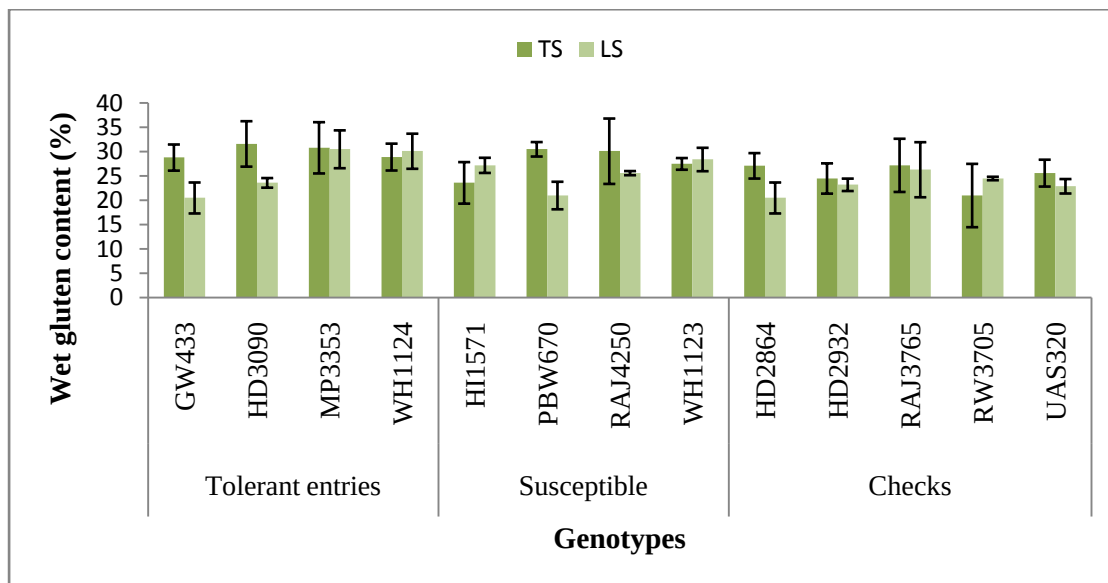


Fig 26c: Content of wet gluten in wheat genotypes under timely and late sown conditions in MLHT I

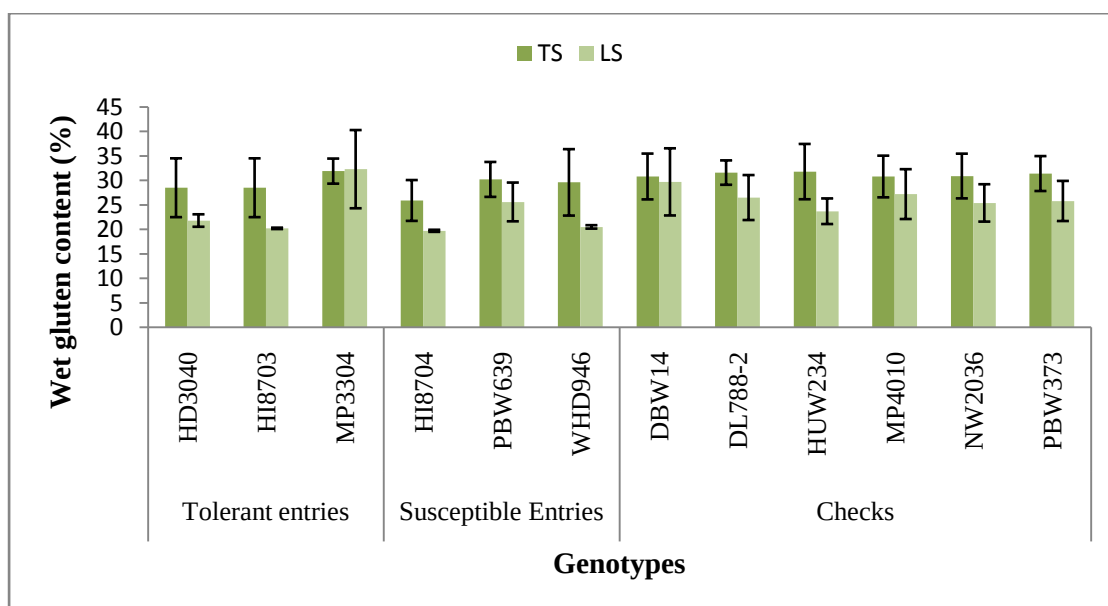


Fig 26d: Content of wet gluten in wheat genotypes under timely and late sown conditions in MLHT II

In MLHT II (Fig 26d), it ranged from 25.9 to 31.6 percent under timely sown conditions with mean value of 30.1 percent. Under late sown conditions, it ranged from 19.7 to 32.3 percent with mean value of 24.8 percent. Tolerant entry MP 3304 had high wet gluten under late sown conditions. It was indicative that higher wet gluten varieties had higher water holding capacity and varieties with low wet gluten suffered irreversible damage to their functional quality owing to heat stress. It was found be significant ($p<0.05$) under both the trials MLHT I and MLHT II.

Table 16a: Gluten content (dry and wet) and Gluten index of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Gluten content (%)				Gluten index	
		Dry		Wet			
		TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	9.4±0.42	9.6±1.56	28.8±2.69	26.7±3.18	98±9.19	87.6±1.84
	HD3090	8.0±0.07	10.2±1.96	31.6±2.67	28.7±0.99	72.8±8.63	65.2±14.00
	MP3353	8.7±1.62	10.3±1.16	30.8±1.29	29.4±3.89	95.2±7.21	92.8±5.52
	WH1124	9.9±1.41	10.3±2.12	28.9±2.76	30.4±3.61	83.2±1.27	91.6±4.67
Susceptible Entries	HI1571	8.0±1.27	9.8±2.81	23.6±2.84	28.4±1.56	95.4±7.35	89.6±3.25
	PBW670	7.0±0.71	10.8±3.39	30.5±1.48	20.5±2.83	85.9±0.64	92.6±5.37
	RAJ4250	10.6±1.3	10.0±1.67	30.1±2.72	23.2±0.42	78.4±4.67	77.6±5.23
	WH1123	9.4±1.36	10.0±2.12	27.5±1.20	26.3±2.40	92.2±5.09	90.3±3.75
Checks	HD2864	8.2±0.42	10.3±1.63	27.1±2.62	20.5±3.18	80.4±3.25	94.6±6.79
	HD2932	9.3±0.64	10.0±1.95	24.5±2.11	30.2±1.27	94±6.36	95.2±7.21
	RAJ3765	9.5±1.54	9.7±1.95	27.2±2.48	28.9±2.66	81.4±2.55	80.7±3.04
	RW3705	9.6±0.28	10.2±1.39	21.0±2.51	24.5±0.35	92.3±5.16	93±5.66
	UAS320	9.6±0.42	10.9±1.88	25.6±2.76	22.9±1.48	90.3±3.75	71.3±9.69
Range		7.0-10.6	9.6-10.9	21.0-31.6	20.5-30.5	72.8-98	65.2-95.2
Mean		9.3	10.2	27.5	24.9	87.6	86.3
CD at 5% Treatments		TS=2.20, LS=2.14		TS=2.43, LS=4.25		TS=2.68, LS=1.58	

Values are mean ± SD of three replicates.

Table 16b: Gluten content (dry and wet) and Gluten index of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Gluten content (%)				Gluten index	
		Dry		Wet			
		TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	9.8±1.56	10.2±2.12	28.5±2.01	21.8±1.27	82.8±1.56	98.8±9.76
	HI8703	8.2±1.69	10.9±0.07	28.5±2.01	20.2±1.14	83.6±0.99	73.1±8.41
	MP3304	9.7±1.13	10.6±2.03	31.9±2.61	32.3±2.99	96.2±7.92	91.0±4.24
Susceptible Entries	HI8704	8.9±1.19	9.9±1.06	25.9±1.17	19.7±1.21	88.4±2.40	80.4±3.25
	PBW639	9.0±0.71	10.2±1.34	30.2±2.16	25.6±2.96	95.0±7.07	84.4±0.42
	WHD946	10.0±1.41	10.6±0.42	29.6±2.79	20.5±0.35	92.3±5.16	95.6±7.50
Checks	DBW14	9.2±0.85	9.8±2.55	30.8±2.83	29.7±2.86	71.0±9.90	83.8±0.85
	DL788-2	9.3±0.49	10.4±1.70	31.6±2.15	26.5±2.60	88.4±2.40	81.9±2.19
	HUW234	9.8±1.56	10.5±2.47	31.8±2.34	23.7±2.62	92.9±5.59	89.9±3.46
	MP4010	9.6±0.28	10.2±2.62	30.8±2.29	27.2±2.09	95.2±7.21	92.6±5.37
	NW2036	9.7±0.92	10.8±2.69	30.9±2.54	25.4±2.82	89.3±3.04	72.0±9.19
	PBW373	10.5±1.06	10.8±0.85	31.4±2.01	25.8±1.10	86.2±0.85	77.3±5.44
Range		8.2-10.5	9.8-10.9	25.9-31.9	19.7-32.3	71.0-96.2	71.98-98.8
Mean		9.5	10.4	30.1	24.8	88.5	86.1
CD at 5% Treatments		TS=1.16, LS=2.61		TS=3.29, LS=2.90		TS=5.28, LS=5.88	

Values are mean ± SD of three replicates.

4.3.8.3 Gluten Index

In MLHT-I (Fig 26e), gluten index ranged from 72.8 to 98.0 under timely sown conditions and 65.2 to 95.2 under late sown conditions with mean values of 87.6 and 86.3 for timely and late sown conditions respectively. The tolerant entry GW 433 had high values of gluten index under timely sown conditions. The varieties had higher gluten index under timely sown conditions than late sown conditions. Majority of varieties show gluten index of more than 75% that considered desirable for bread making.

In MLHT-II (Fig 26e), the gluten index ranges from 71.0 to 96.2 under timely sown and 72.0 to 98.8 under late sown conditions with mean values of 88.5 and 86.1 for timely and late sown respectively.

The tolerant entry MP 3304 and HD 3040 were found to be best under different environmental conditions. It was found be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

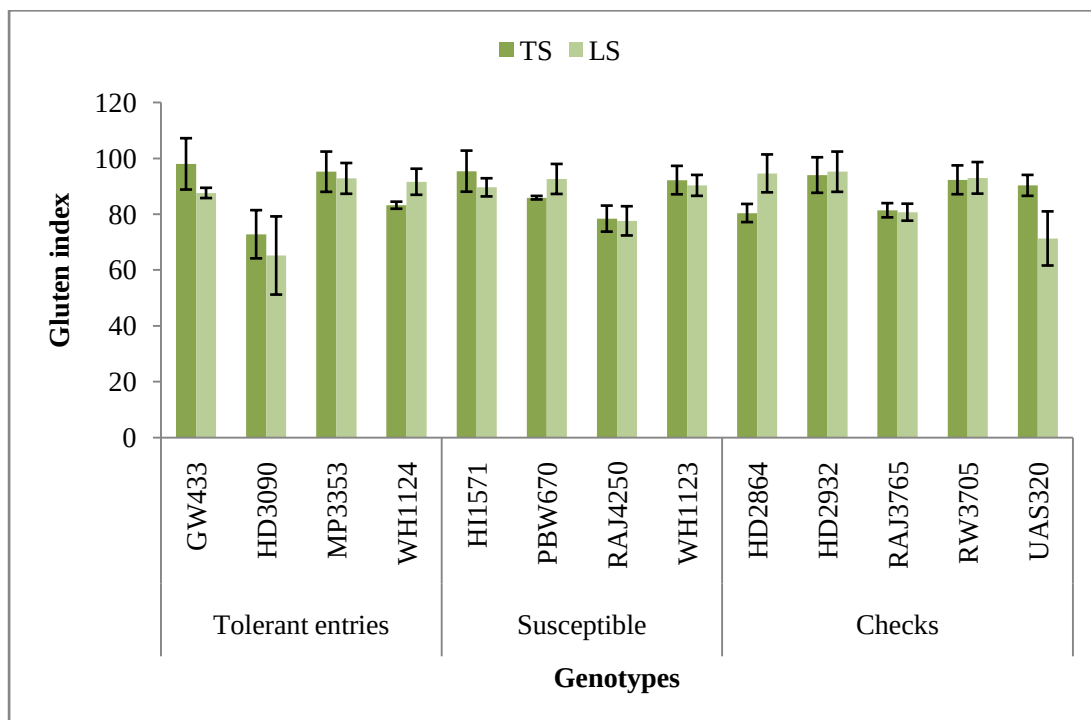


Fig 26e: Gluten index of wheat genotypes under timely and late sown conditions in MLHT I

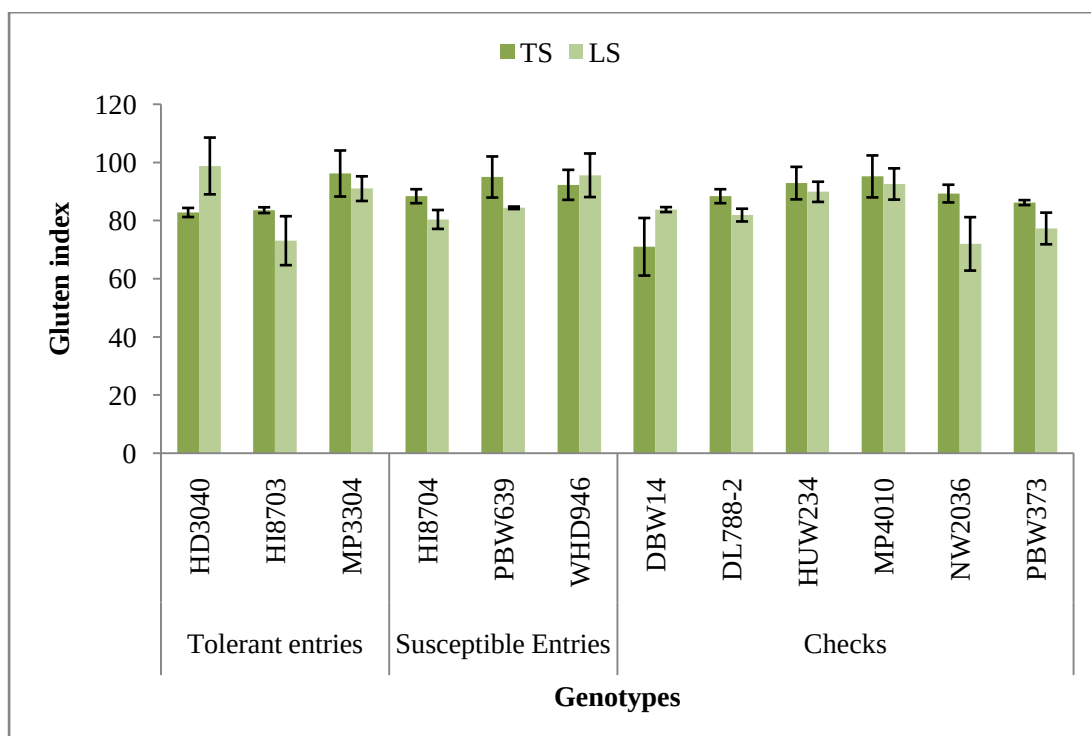


Fig 26f: Gluten index of wheat genotypes under timely and late sown conditions in MLHT II

4.3.9 Total Sugars

In MLHT-I (table 17a), total sugars ranges from 14.51 to 16.64 mg/g under timely sown and 33.26 to 128.8 mg/g under late sown conditions with mean value of 34.40 and 93.53 mg/g for timely and late sown conditions, respectively. The susceptible entry RAJ4250, WH1123 and check variety RAJ3765 had higher sugar content under timely sown conditions. The entry HD2864 had high sugar content among late sown conditions.

Table 17a: Content of total sugars in grains of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Total Sugars	
		TS	LS
Tolerant entries	GW433	24.51±7.42	72.78±8.64
	HD3090	26.69±1.20	128.8±30.97
	MP3353	23.09±1.35	72.03±9.17
	WH1124	32.09±5.01	112.04±19.12
Susceptible entries	HI1571	36.75±8.31	116.77±22.46
	PBW670	30.29±3.74	126.30±29.20
	RAJ4250	64.64±28.03	114.98±21.20
	WH1123	50.21±17.83	88.04±2.15
Checks	HD2864	45.65±14.60	124.82±28.16
	HD2932	42.28±12.22	110.59±18.09
	RAJ3765	46.29±15.05	42.54±30.02
	RW3705	37.49±8.83	72.96±8.51
	UAS320	36.23±7.94	33.26±36.59
Range		23.09-64.64	33.26-128.8
Mean		34.40	93.53
CD at 5% Treatments		TS=3.19,LS=4.40	

Values are mean ± SD of three replicates.

Sugars units are expressed as mg/g

In MLHT-II (table 17b), the sugar content ranged from 9.32 to 107.69 mg/g and 16.41 to 134.11mg/g under timely and late sown conditions, respectively. The mean value under timely sown conditions was 23.88 mg/g and for late sown conditions, it was 70.8. mg/g. It implies that sugar content was significant ($p<0.05$) under heat stress. The varieties (Fig 27a, b) had higher sugar content under late sown conditions.

Table 17b: Content of total sugars in grains of wheat genotypes under timely and late sown conditions in MLHT II

Genotypes		Total sugars	
		TS	LS
Tolerant entries	HD3040	27.58±1.71	82.82±0.13
	HI8703	29.32±7.55	106.23±16.43
	MP3304	29.87±6.98	54.43±20.20
Susceptible entries	HI8704	20.13±0.09	84.11±0.78
	PBW639	11.54±5.98	53.04±21.18
	WHD946	16.34±2.59	60.60±15.84
Checks	DBW14	22.71±5.15	72.50±7.42
	DL788-2	16.41±2.83	107.69±16.97
	HUW234	17.50±1.77	64.14±13.34
	MP4010	16.94±2.16	74.12±6.28
	NW2036	15.04±3.51	134.11±36.14
	PBW373	11.90±5.73	47.09±25.39
Range		11.54-29.87	47.09-134.11
Mean		23.88	70.8
CD at 5% Treatments		TS=4.01,LS=2.40	

Values are mean ± SD of three replicates.
Sugars units are expressed as mg/g

The levels of sugars can increase under stress, which might be a signal possibly developmentally regulated, modulated by the sugar pool and implying genetic variability in *Triticum* species (Leon and Sheen 2003; Dias *et al* 2009).

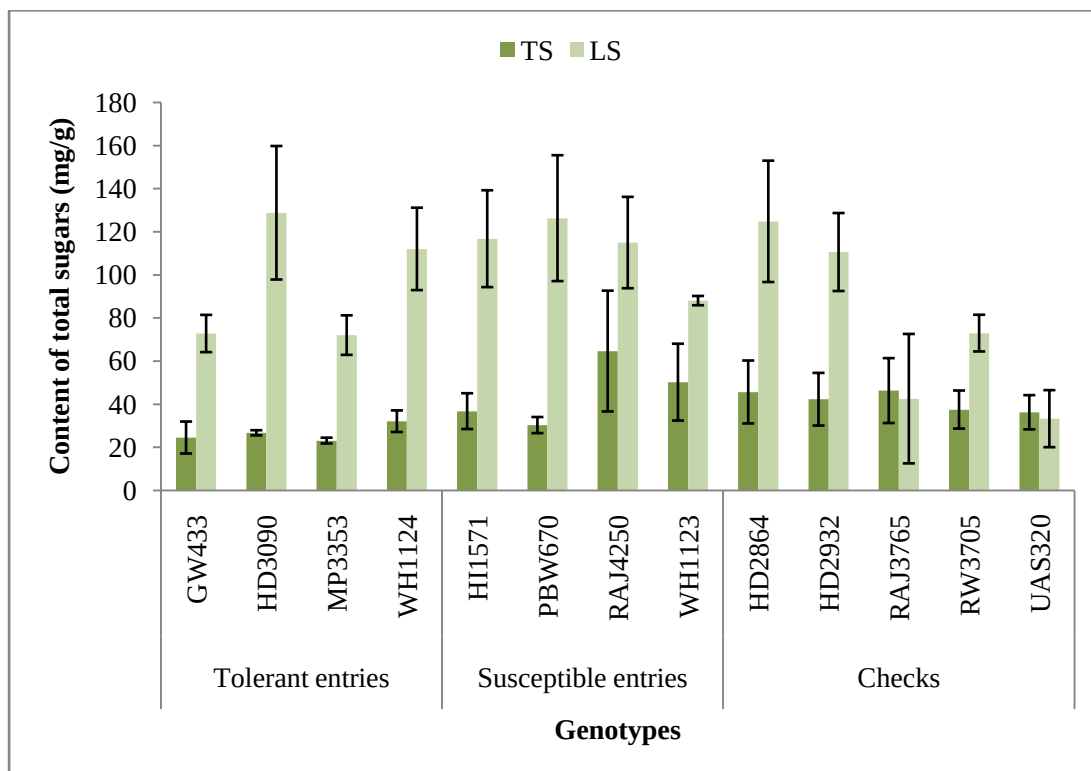


Fig 27a: Content of total sugars in grains of wheat genotypes under timely and late sown conditions in MLHT I

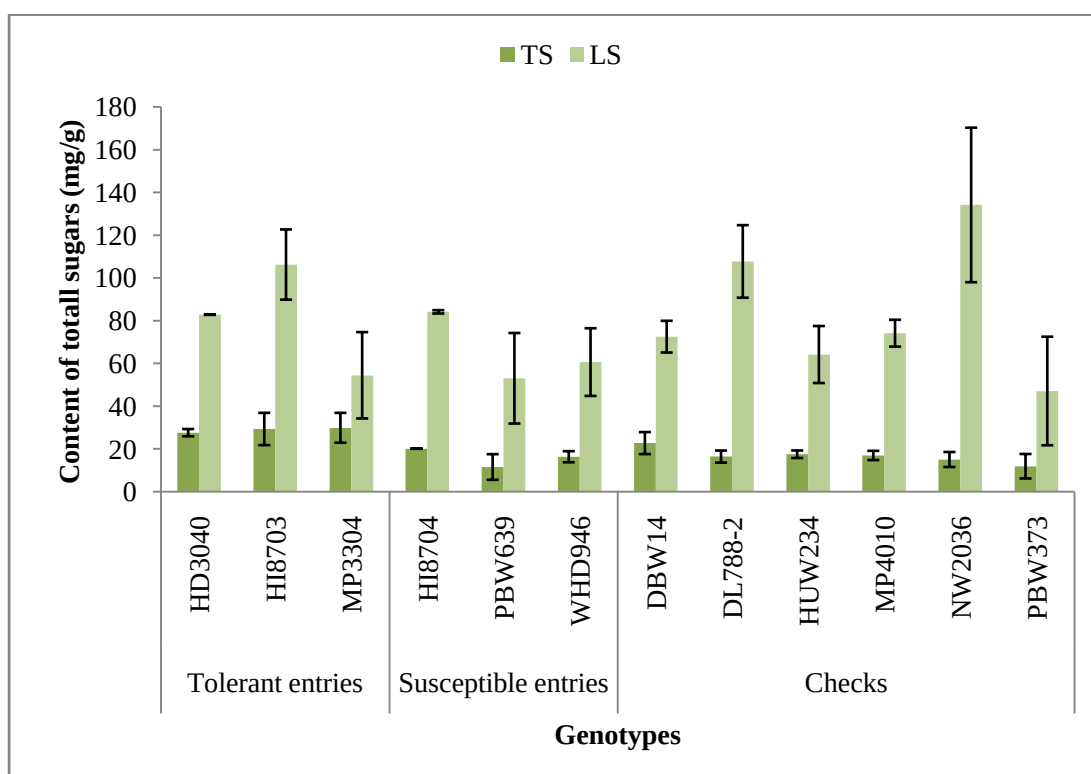


Fig 27b: : Content of total sugars in grains of wheat genotypes under timely and late sown conditions in MLHT II

4.3.10 Starch Pasting Characteristics

The rapid visco analyzer (RVA) is an effective instrument for measuring the viscous properties of flour and for relating functionality to structural properties. Starch pasting characteristics were depicted in Table 18a, b, c and d.

4.3.10.1 Pasting Temperature

Pasting temperature (PT) provides an indication of the minimum temperature required to cook a given sample. In MLHT-I (Fig 28a). The paste temperature had a range from 65.2 to 71.2 °C under timely sown and 68.4 to 71.2°C under late sown conditions with mean value of 69.4 and 69.9 °C for timely and late sown conditions, respectively.

Table 18a: Starch pasting characteristics (pasting temperature, peak viscosity and hold viscosity) of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Pasting temp. (°C)		Peak viscosity (cp)		Hold viscosity (cp)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	70.4±1.70	69.2±0.85	2897±72.83	3172±121.62	2106±74.95	2229±161.93
	HD3090	67.2±0.57	68.8±0.57	2516±342.24	2777±157.68	1622±267.29	1847±108.19
	MP3353	65.2±1.98	70.0±1.41	3229±161.93	2709±205.77	2291±205.77	1656±243.24
	WH1124	69.2±0.85	70.0±1.41	3159±112.43	3266±188.09	2124±87.68	2025±17.68
Susceptible entries	HI1571	68.4±0.28	69.2±0.85	3112±79.20	2879±85.56	1915±60.10	1837±115.26
	PBW670	69.2±0.85	68.4±0.28	3655±463.15	3731±5.90	2411±290.62	2396±280.01
	RAJ4250	70.8±1.98	70.4±1.70	3655±463.15	3558±394.57	2142±100.41	2074±52.33
	WH1123	69.6±1.13	70.8±1.98	3433±306.18	3318±224.86	2134±94.75	1952±33.94
Checks	HD2864	70.4±1.70	70.4±1.70	3135±95.46	3161±113.84	1970±21.21	2001±0.71
	HD2932	70.4±1.70	71.2±2.26	2921±55.86	2939±43.13	1957±30.41	1970±21.21
	RAJ3765	70.4±1.70	70.4±1.70	2970±21.21	3558±394.57	1928±50.91	2074±52.33
	RW3705	71.2±2.26	70.0±1.41	2965±24.75	3091±64.35	2116±82.02	2053±37.48
	UAS320	70.0±1.41	70.0±1.41	2417±412.24	3091±64.35	1474±371.94	2053±37.48
Range		65.2-71.2	68.4-71.2	2417-3655	2709-3731	1474-2411	1656-2396
Mean		69.4	69.9	3081	3173	2014	2012
CD at 5% Treatments		TS=2.54	LS=NS	TS=4.58	LS=13.72	TS=10.17	LS=6.56

Values are mean ± SD of three replicates.

In MLHT-II (Fig 28b), The peak temperature ranges from 65.2 to 70.4°C under timely sown conditions and 66.1 to 71.6 °C under late sown conditions with a mean value of 69.1 and 69.9 °C, respectively. The entry MP 3304, HUW 234 and PBW 639 were the best entries under the effect of different environments. It was found be non significant ($p<0.05$) under both the trials MLHT I and MLHT II.

Table 18c: Starch pasting characteristics (pasting temperature, peak viscosity and hold viscosity) of wheat genotypes under timely and late sown conditions in MLHT II

VARIETY		Paste temp. (°C)		Peak viscosity (cp)		Hold viscosity (cp)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	65.2±0.14	70.8±4.10	3574±52.33	3655±109.60	2445±38.89	2299±142.13
	HI8703	68.0±2.12	70.4±3.82	3242±182.43	3088±291.33	2440±42.43	2223±195.87
	MP3304	70.4±3.82	70.8±4.10	3313±132.23	3232±189.50	2132±260.22	1972±373.35
Susceptible entries	HI8704	70.0±3.54	66.1±0.78	2999±354.26	2983±365.57	2202±210.72	1964±379.01
	PBW639	70.4±3.82	70.8±4.10	3258±171.12	3174±230.52	2077±299.11	1978±369.11
	WHD946	69.6±3.25	69.2±2.97	2892±429.92	3044±322.44	2014±343.65	2067±306.18
Checks	DBW14	69.2±2.97	70.8±4.10	3919±296.28	3786±202.23	2589±62.93	2385±81.32
	DL788-2	69.2±2.97	71.2±4.38	3608±76.37	3456±31.11	2401±70.00	2205±208.60
	HUW234	70.4±3.82	71.6±4.67	3443±40.31	3537±26.16	2155±243.95	2184±223.45
	MP4010	68.8±2.69	69.6±3.25	3185±222.74	3276±158.39	2020±339.41	2014±343.65
	NW2036	68.8±2.69	66.7±1.20	2537±680.97	3071±303.35	1957±383.96	1941±395.27
	PBW373	69.6±3.25	71.2±4.38	2751±529.62	3360±98.99	1831±473.96	2312±132.94
Range		65.2-70.4	66.1-71.6	2537-3919	2983-3786	1831-2589	1941-2385
Mean		69.1	69.9	3226	3305	2188	2128
CD at 5% Treatments		TS=NS	LS=NS	TS=10.67	LS=7.69	TS=17.97	LS=16.21

Values are mean ± SD of three replicates.

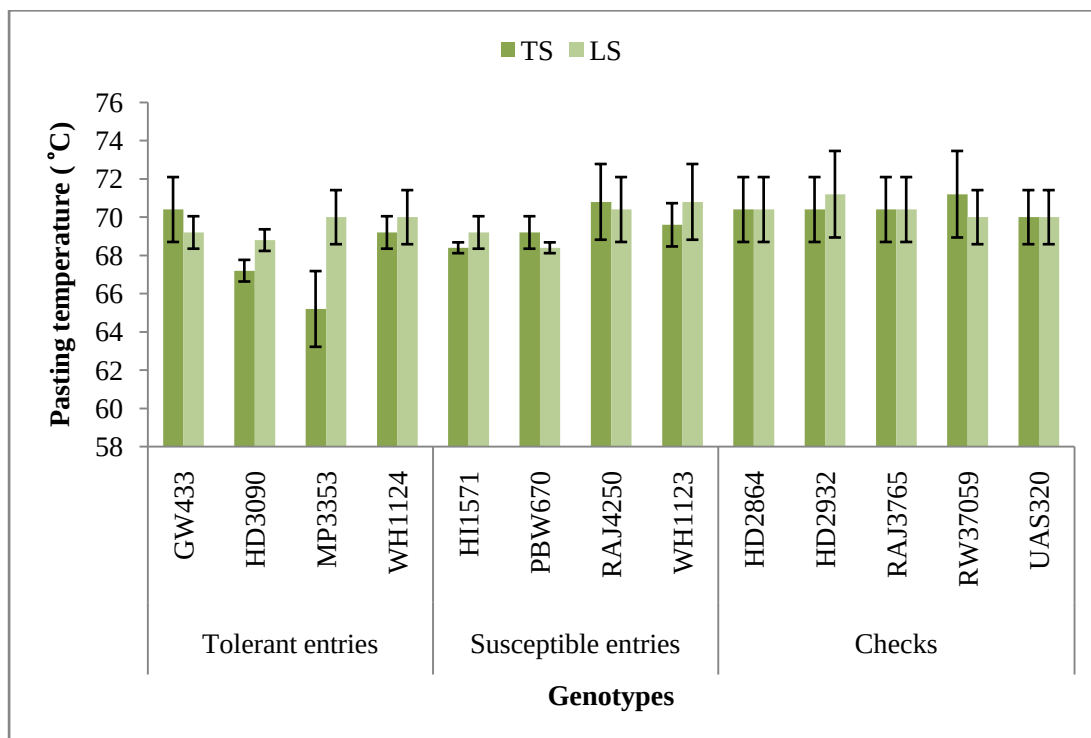


Fig 28a: Pasting temperature of wheat genotypes under timely and late sown conditions in MLHT I

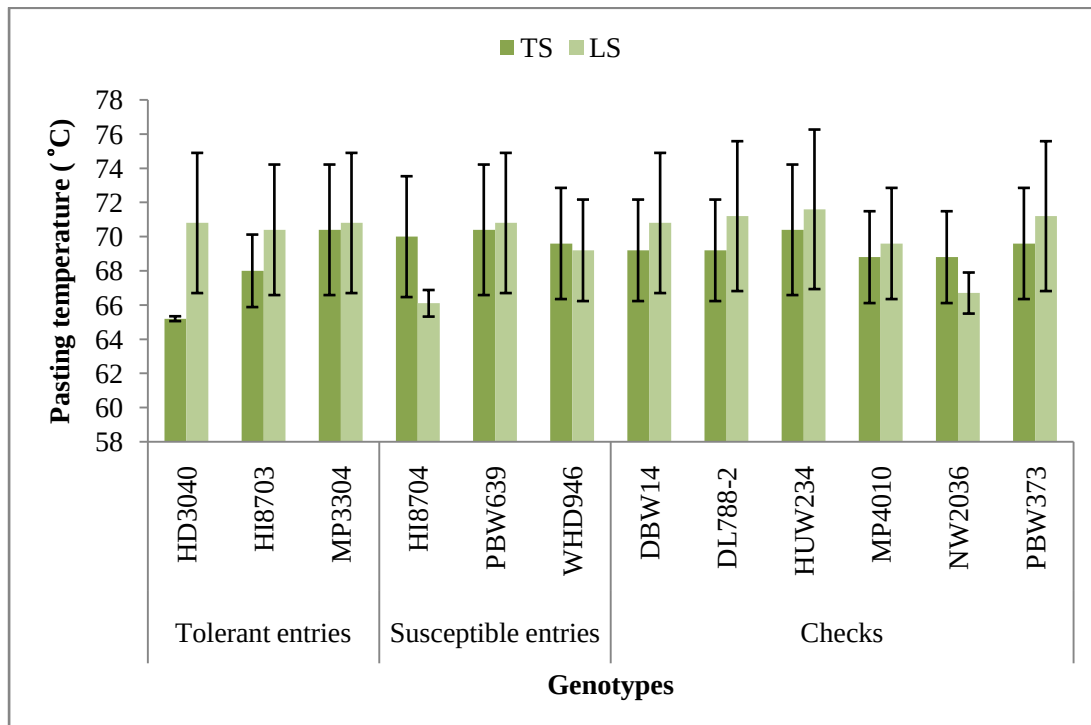


Fig 28b: Pasting temperature of wheat genotypes under timely and late sown conditions in MLHT II

4.3.10.2 Peak Viscosity

Peak viscosity (PV) indicates the water binding capacity of the starch whereas final viscosity (FV) depicts the ability of starch to form a viscous paste after cooking and cooling. In MLHT-I (Fig 28c), the peak viscosity ranges from 2417 to 3655 cp and 2709 to 3731 cp for timely and late sown conditions, respectively with mean values of 3081 and 3173 cp. The entry RAJ 4250 had high peak value viscosity having a value of 3655 cp under timely sown conditions and entry PBW 670 under late sown condition having a value of 3731 cp.

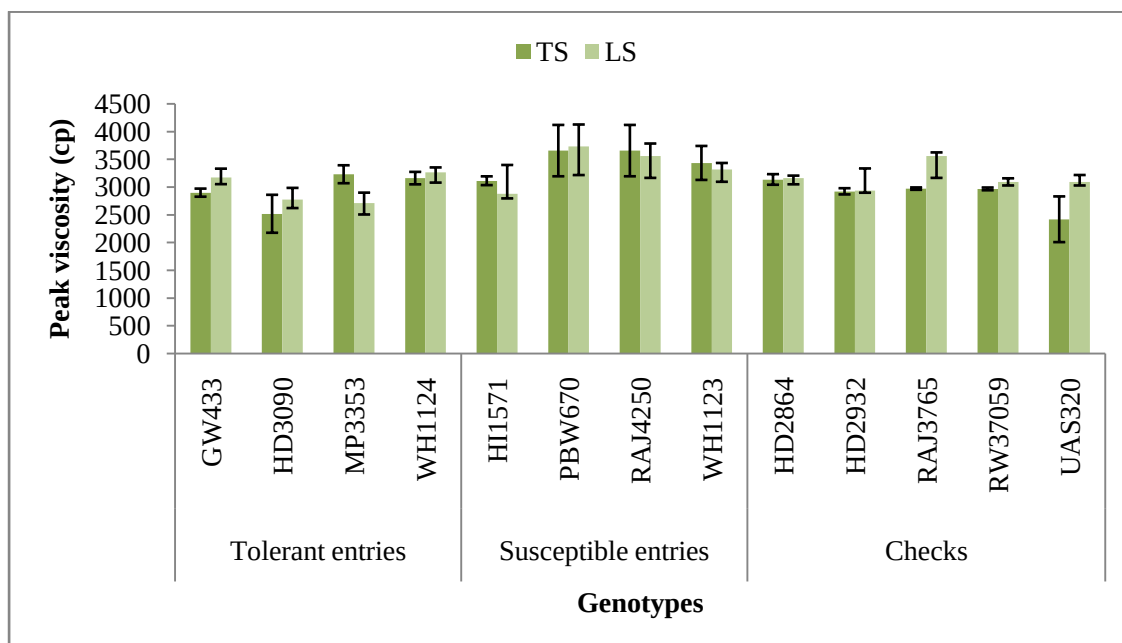


Fig 28c: Peak viscosity of wheat genotypes under timely and late sown conditions in MLHT I

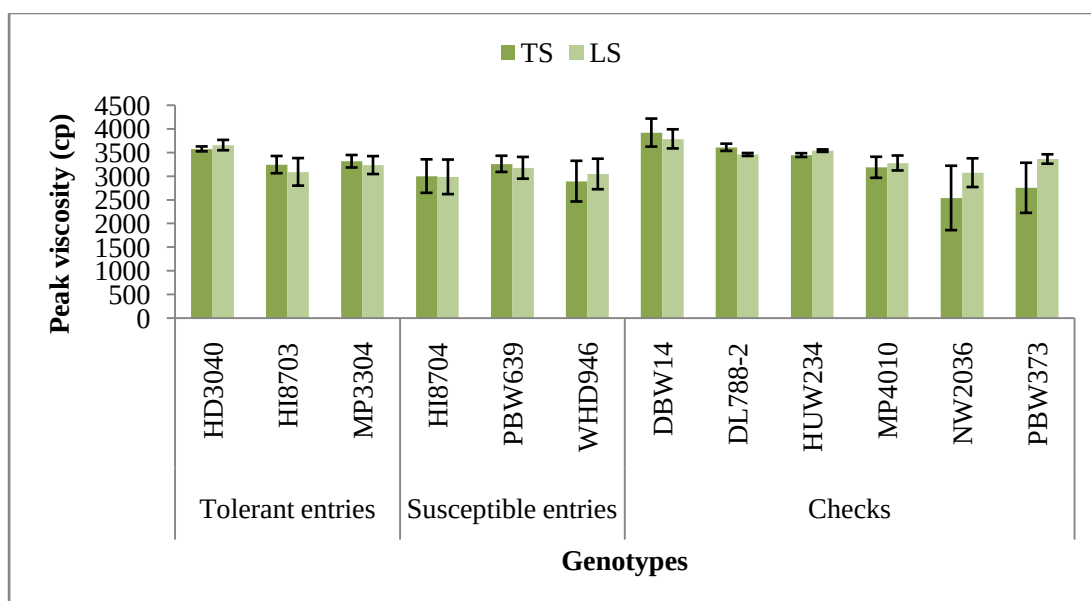


Fig 28d: Peak viscosity of wheat genotypes under timely and late sown conditions in MLHT II

In MLHT-II(Fig 28d), the peak viscosity ranges from 2537 to 3919 cp and 2983 to 3786 cp for timely and late sown conditions respectively, with mean value of 3226 and 3305 cp. The variety DBW14 had the highest peak viscosity under timely and late sown conditions. It was found be significant ($p<0.05$) under both the trials MLHT I and MLHT II.

Table 18b: Starch pasting characteristics (final viscosity, breakdown and setback) of wheat genotypes under timely and late sown conditions in MLHT I

Genotypes		Final viscosity (cp)		Breakdown (cp)		Setback (cp)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	GW433	3786±202.23	4005±357.09	791±6.36	943±101.12	1680±56.57	1776±124.45
	HD3090	3025±335.88	3310±134.35	894±66.47	930±91.92	1403±139.30	1463±96.87
	MP3353	3621±85.56	2897±426.39	938±97.58	1053±178.90	1330±190.92	1241±253.85
	WH1124	3694±137.18	3582±57.98	1035±166.17	1241±311.83	1570±21.21	1260±240.42
Susceptible entries	HI1571	3297±143.54	3138±255.97	1197±280.72	1042±171.12	1382±154.15	1301±211.42
	PBW670	3853±249.61	3780±197.99	1244±313.96	1335±378.30	1424±124.45	1384±152.74
	RAJ4250	3558±41.01	3344±110.31	1513±504.17	1484±483.66	1416±130.11	1270±233.35
	WH1123	3511±7.78	3213±202.94	1299±352.85	1366±400.22	1377±157.68	1261±239.71
Checks	HD2864	3616±82.02	3634±94.75	1165±258.09	1160±254.56	1646±32.53	1633±23.33
	HD2932	3480±14.14	3514±9.90	964±115.97	969±119.50	1523±54.45	1544±39.60
	RAJ3765	3287±150.61	3344±110.31	1042±171.12	1484±483.66	1359±170.41	1270±233.35
	RW3705	3725±159.10	3639±98.29	849±34.65	1038±168.29	1609±6.36	1586±9.90
	UAS320	2863±450.43	3639±98.29	943±101.12	1038±168.29	1389±149.20	1586±9.90
Range		2863-3853	2897-4005	791-1513	930-1484	1330-1680	1241-1776
Mean		3485	3664	1067	1160	1469	1428
CD at 5% Treatments		TS=11.74	LS=13.97	TS=13.32	LS=11.37	TS=11.92	LS=9.43

Values are mean ± SD of three replicates.

Table 18d: Starch pasting characteristics (final viscosity, breakdown and setback) of wheat genotypes under timely and late sown conditions in MLHT II

VARIETY		Final viscosity (cp)		Breakdown (cp)		Setback (cp)	
		TS	LS	TS	LS	TS	LS
Tolerant entries	HD3040	4052±36.77	3885±81.32	1129±50.20	1356±110.31	1607±4.95	1586±9.90
	HI8703	4117±82.73	3976±16.97	802±281.43	865±236.88	1677±54.45	1753±108.19
	MP3304	3543±323.15	3300±494.97	1181±13.44	1260±42.43	1411±133.64	1328±192.33
Susceptible entries	HI8704	3908±65.05	3686±222.03	790±289.91	964±166.88	1706±74.95	1826±159.81
	PBW639	3454±386.08	3294±499.22	1181±13.44	1196±2.83	1377±157.68	1316±200.82
	WHD946	3715±201.53	3898±72.12	878±227.69	977±157.68	1701±71.42	1831±163.34
Checks	DBW14	3937±44.55	3898±72.12	1330±91.92	1401±142.13	1348±178.19	1513±61.52
	DL788-2	3746±179.61	3634±258.80	1207±4.95	1251±36.06	1345±180.31	1429±120.92
	HUW234	3639±255.27	3681±225.57	1288±62.23	1353±108.19	1484±82.02	1497±72.83
	MP4010	3456±384.67	3472±373.35	1165±24.75	1262±43.84	1436±115.97	1458±100.41
	NW2036	3339±467.40	3385±434.87	580±438.41	1197±2.12	1382±154.15	1328±192.33
	PBW373	3216±554.37	3720±197.99	920±197.99	1048±107.48	1385±152.03	1408±135.76
Range		3216-4117	3294-3976	580-1330	865-1401	1345-1706	1316-1831
Mean		3676	3652	1037	1177	1488	1522
CD at 5% Treatments		TS=9.41	LS=10.06	TS=8.34	LS=4.73	TS=7.85	LS=4.26

Values are mean ± SD of three replicates.

4.3.10.3 Hold Viscosity

The hold viscosity (HV) indicates the ability of a sample to withstand the heating and shear stress. In MLHT-I (Fig 28e), it ranged from 1474 to 2411 cp and 1656 to 2396 cp for timely & late sown condition with mean value of 2014 and 2012 cp respectively. The susceptible entry PBW670 had the highest values of holding viscosity i.e. 2411 and 2396 cp for timely and late sown conditions, respectively.

In MLHT-II (Fig 28f), It ranges from 1831 to 2589 cp under timely sown conditions and 1941 to 2385 cp under late sown conditions with a mean value of 2188 and 2128 cp. The DBW14 check variety had the highest hold viscosity under both timely and late sown

condition and it is good for chapatti making. It was found be significant ($p<0.05$) under both the trials MLHT I and MLHT II.

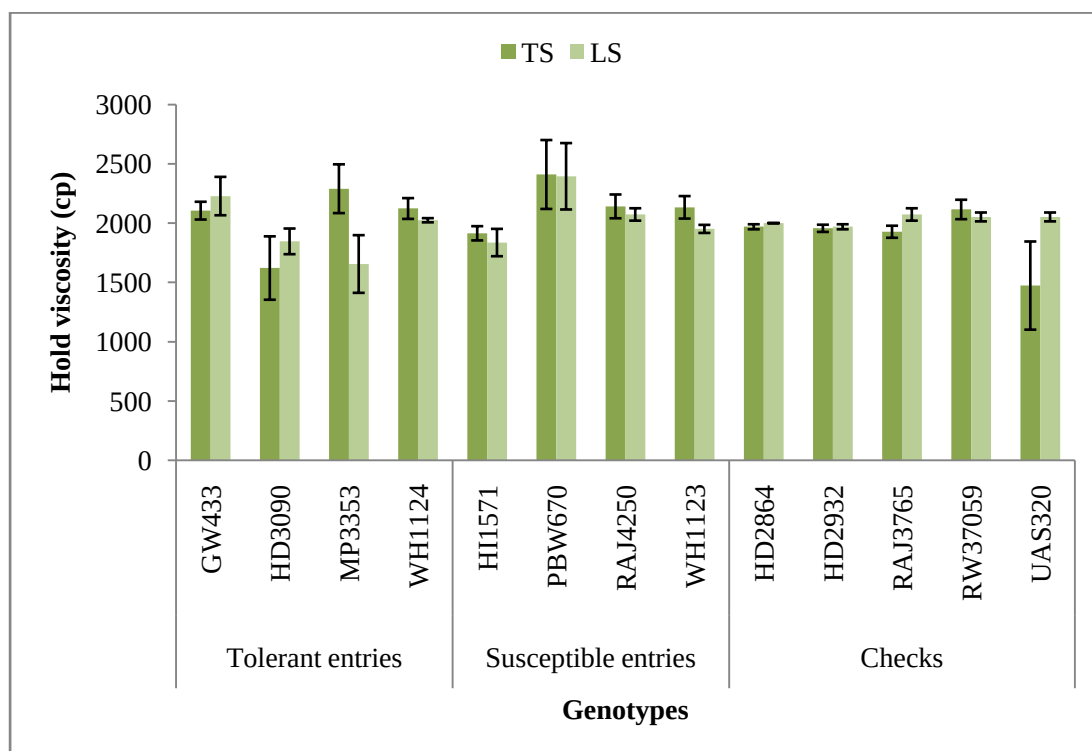


Fig 28e: Hold viscosity of wheat genotypes under timely and late sown conditions in MLHT I

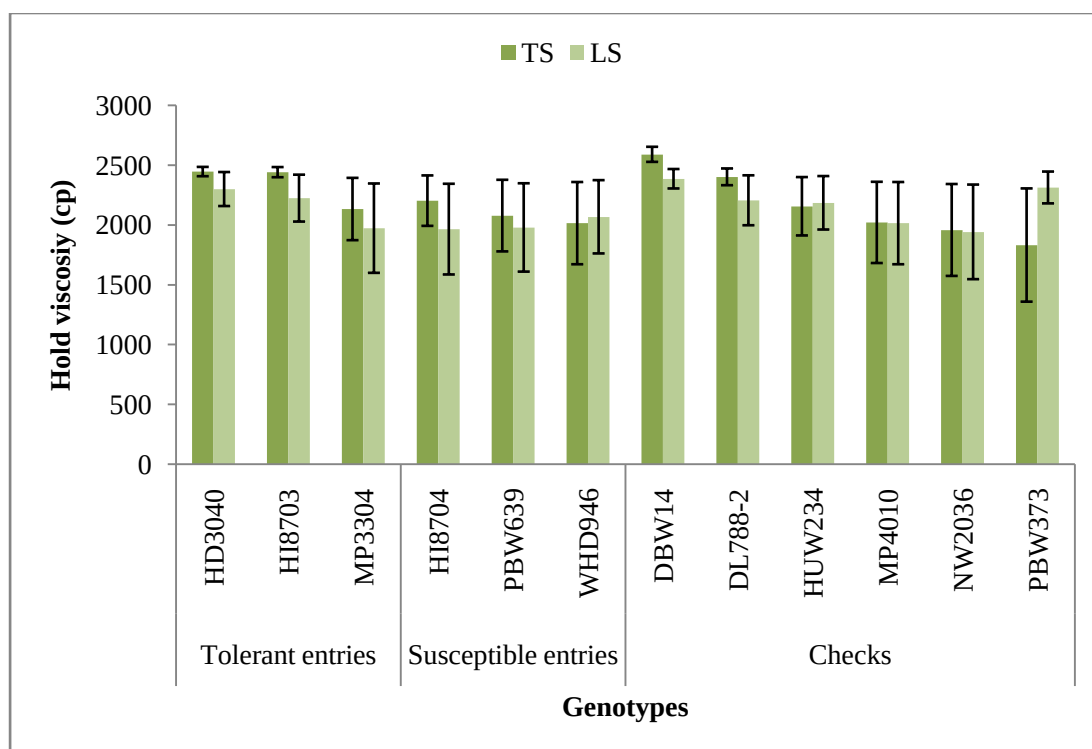


Fig 28f: Hold viscosity of wheat genotypes under timely and late sown conditions in MLHT II

4.3.10.4 Final Viscosity

In MLHT-I (Fig 28g), it ranges from 2863 to 3853 cp and 2897 to 4005 cp with mean values of 3485 and 3664 cp under timely and late sown conditions, respectively. The susceptible entry PBW670 had highest final viscosity having a value of 4005. So the heat stress found to be significant for final viscosity. So under late sown conditions, the mean value of final viscosity was found to be higher due heat stress.

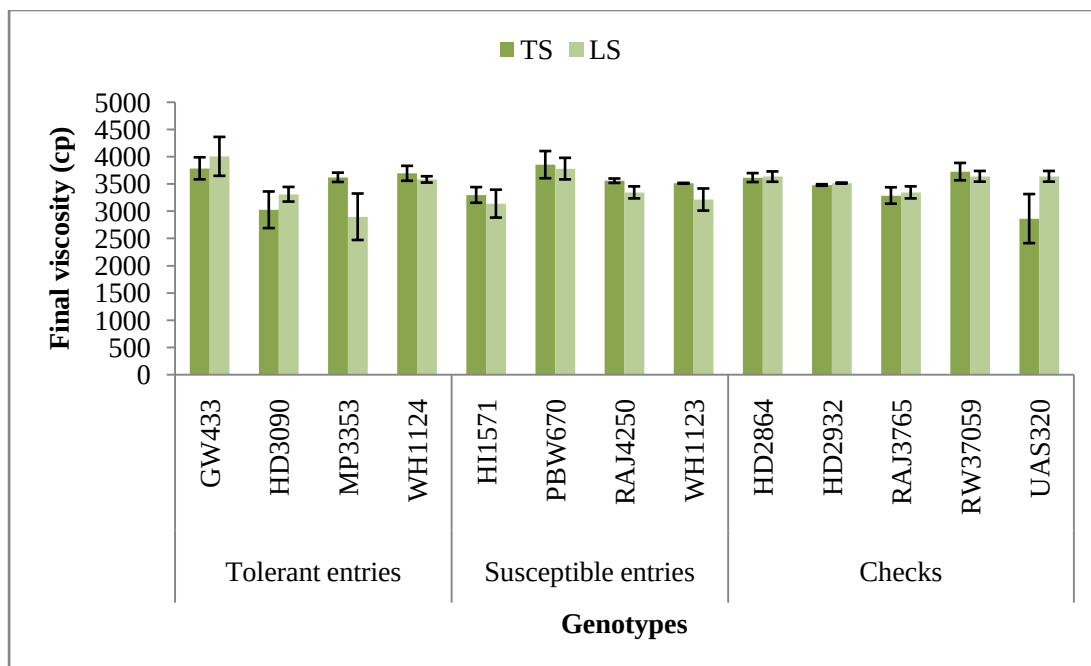


Fig 28g: Final viscosity of wheat genotypes under timely and late sown conditions in MLHT I

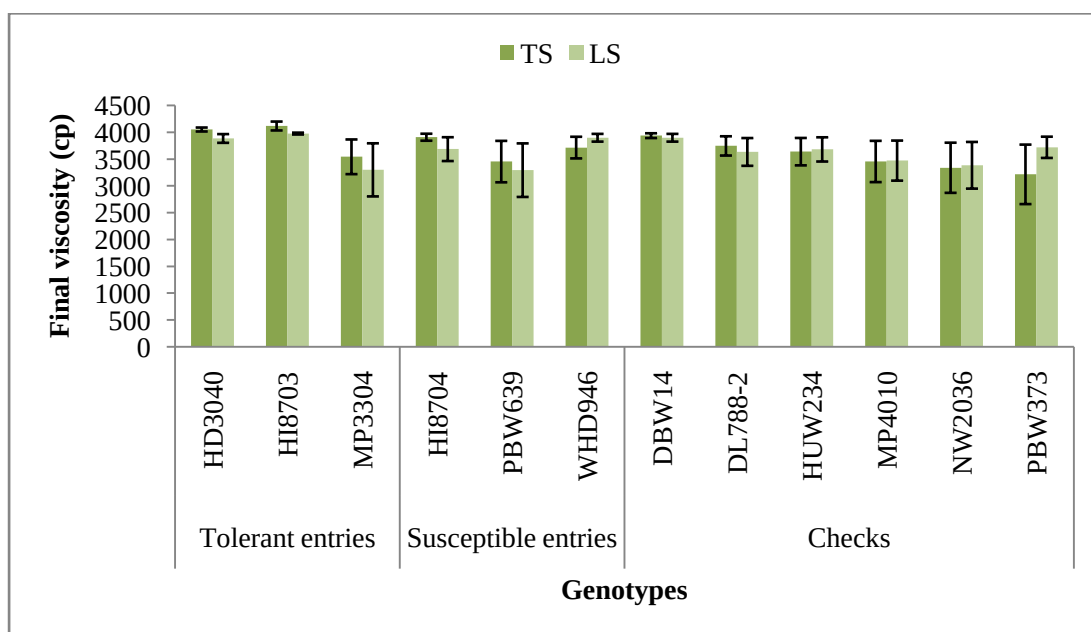


Fig 28h: Final viscosity of wheat genotypes under timely and late sown conditions in MLHT II

In MLHT-II (Fig 28h), it ranges from 3216 to 4117 cp under timely sown conditions and 3294 to 3976 cp under late sown conditions with mean values of 3676 and 3652 cp, respectively. The highest values were recorded for tolerant entry HI8703 under both timely and late sown conditions. It was found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

4.3.10.5 Breakdown

Starch granules with lower breakdown values reflect higher stability and may have good potential as a food ingredient for food exposed to heat treatment at high temperature and mechanical stirring. In MLHT-I (Fig 28i), breakdown ranges from 791 to 1513 cp and 930 to 1484 cp for timely and late sown conditions respectively with mean values of 1067 and 1160 cp, the breakdown did not get affected in heat stress and found to be non-significant as there was no alteration in composition of starch content susceptible entry RAJ4250 had highest breakdown under both timely and late sown conditions.

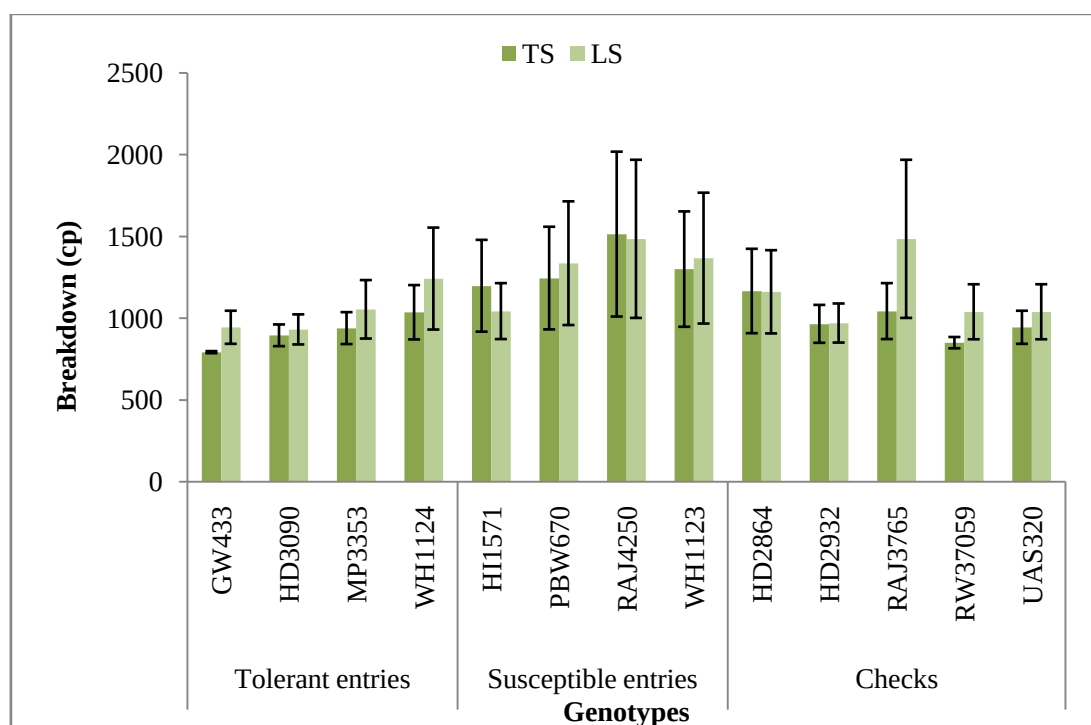


Fig 28i: Breakdown of wheat genotypes under timely and late sown conditions in MLHT I

In MLHT-II (Fig 28j), it ranges from 580 to 1330 cp with mean value of 1037 cp under timely sown and 865 to 1401 cp with mean value of 1177 cp under late sown conditions. The check variety DBW14 had the highest breakdown value for both timely and late sown condition. It was found to be significant ($p < 0.05$) under both the trials MLHT I and MLHT II.

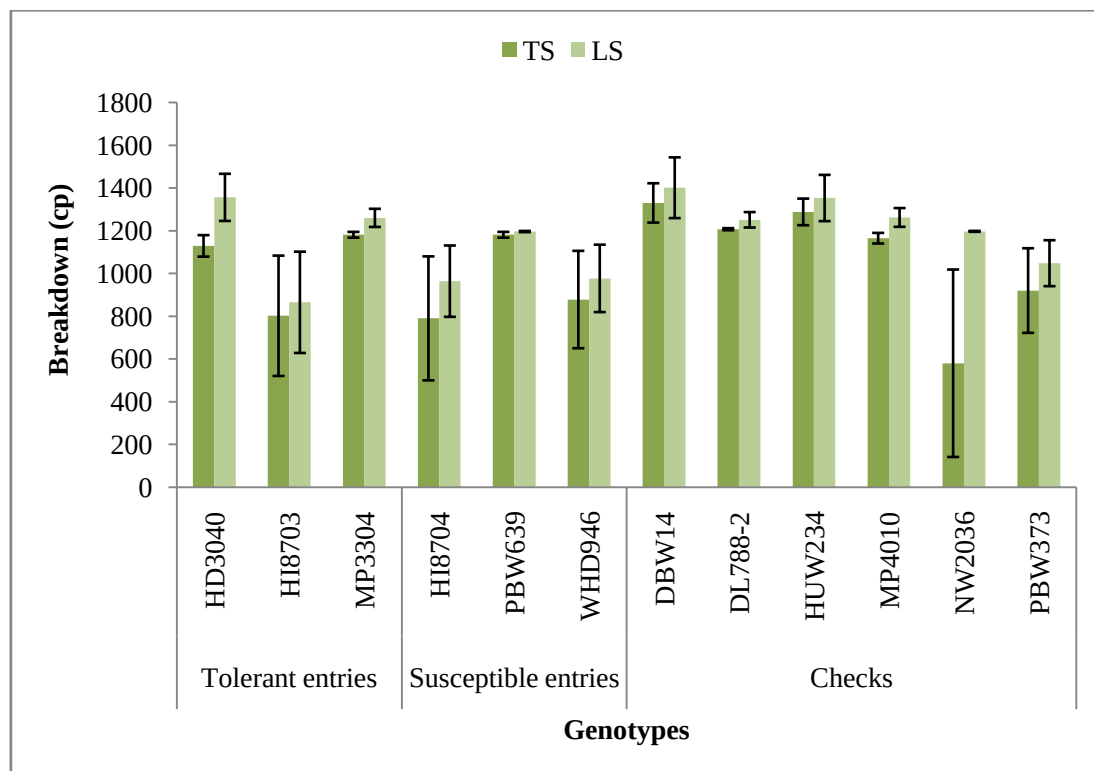


Fig 28j: Breakdown of wheat genotypes under timely and late sown conditions in MLHT II

4.3.10.6 Setback

During cooling, re-association between starch molecules, especially amylose, will result in the formation of a gel structure and thereby increasing viscosity which is referred as FV. This phase is commonly described as the setback (SB) region and is related to retrogradation and reordering of starch molecules. The low setback values indicate low rate of starch retrogradation. In MLHT-I (Fig 28k), the setback value ranged from 1330 to 1680 cp under timely sown and 1241 to 1776 cp under late sown conditions with mean values of 1469 and 1428 cp, respectively. The tolerant entry GW433 had the highest setback value of 1680 and 1778 cp under timely and late sown conditions. The setback was found to be non significant under heat stress.

In MLHT-II (Fig 28l), the setback ranges from 1345 to 1706 cp and 1316 to 1831 cp under timely and late sown conditions respectively with mean values of 1488 and 1522 cp. The susceptible entries HI8704 and WHD946 had highest setback under timely and late sown conditions, respectively. The setback was affected by date of sowing. So It was found be significant ($p < 0.05$) under both the trials MLHT I and MLHT II. The variety had lower setback value are fulfilled for processing as their slurry/paste changes little after cooking.

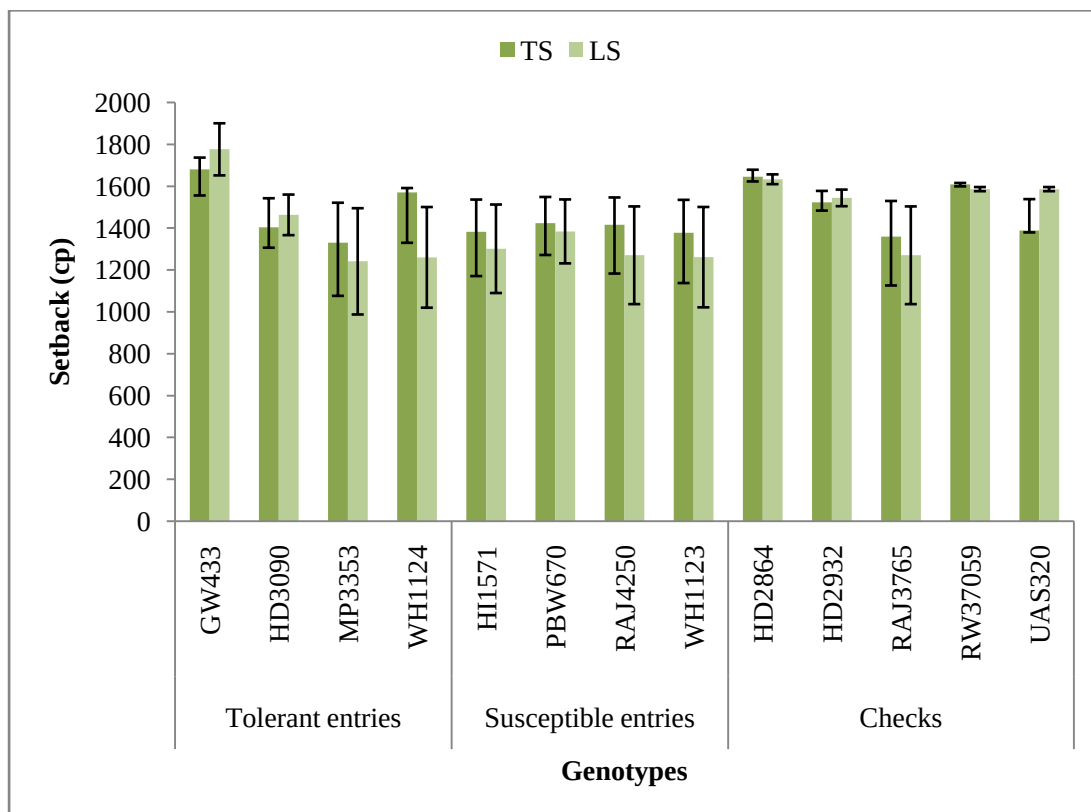


Fig 28k: Setback of wheat genotypes under timely and late sown conditions in MLHT I

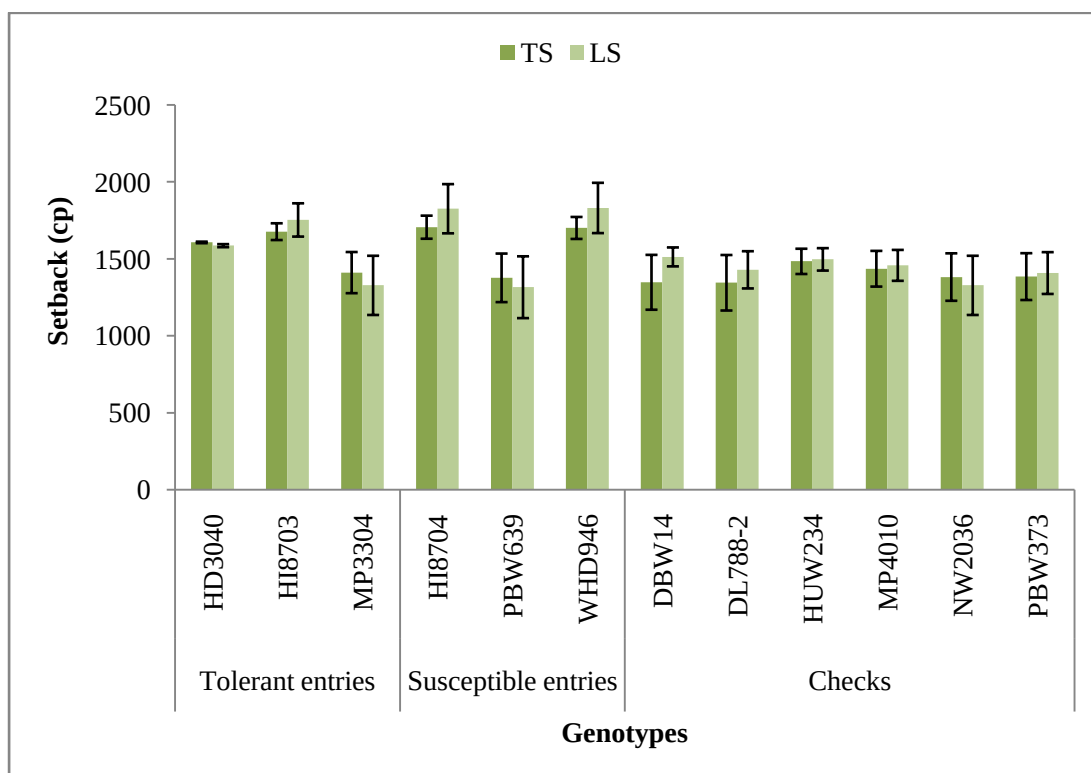


Fig 28l: Setback of wheat genotypes under timely and late sown conditions in MLHT II

Blumenthal *et al* (1993) observed that as the temperature during grain filling increases, the relative proportion of protein to starch also increases with increase in temperature up to 30°C the extent of both protein and starch synthesis is reduced, with starch being more affected than proteins.

4.3.11 Correlation coefficients between different quality characteristics

Correlation depicted in Table 19a, b and 20a, b of trial MLHT I and MLHT II was found from means of all characteristics and showed different behaviors. In MLHT I, under timely sown conditions, test weight revealed positive correlation with SDS-sedimentation value ($r=0.566$) and proteins also exhibited positive correlation with SDS-sedimentation value ($r=.675$). Proteins also exhibited positive correlation with grain appearance score ($r=0.628$) and phenol reaction score ($r=0.564$). Phenol reaction score revealed negative correlation with kernel hardness ($r= -0.634$).

Under late sown conditions, SDS-sedimentation value exposed negative correlation with kernel hardness and positively correlate with proteins ($r=0.750$). Proteins also showed negative correlation with kernel hardness ($r=0.774$). Gluten index showed negative correlation with grain appearance score ($r=-0.553$).

In MLHT II, under timely sown conditions SDS-sedimentation value demonstrated positive correlation with phenol reaction score ($r=0.656$) and proteins ($r=0.598$). Phenol reaction score exhibited positive correlation with kernel hardness ($r=0.613$) and proteins exhibited positive correlation with kernel hardness ($r=.590$) and phenol reaction score ($r=0.895$). Sugars exhibited negative correlation with gluten index ($r= -0.754$).

Under late sown conditions, phenol reaction score exhibited positive correlation with test weight ($r=0.632$). Grain appearance score exhibited positive correlation with Test weight ($r=0.726$) and phenol reaction score ($r=0.936$). Gluten index exhibited positive correlation with Phenol reaction score ($r= -0.594$).

Table 19a: Correlation coefficients between SDS-sedimentation value, test weight, grain hardness, phenol reaction score, grain appearance score, gluten index, total proteins and total sugars under timely sown conditions in MLHT I.

	SDS-Sedimentation Value	Test Weight	Grain Hardness	Phenol Reaction Score	Grain Appearance Score	Gluten Index	Protein Content
Test Weight	0.566						
Grain Hardness	-0.439	-0.146					
Phenol Reaction Score	0.533	0.246	-0.634				
Grain Appearance Score	0.418	0.438	0.028	-0.016			
Gluten Index	0.128	0.177	0.323	-0.090	-0.249		
Protein Content	0.675	0.487	-0.273	0.564	0.628	-0.406	
Total Sugars	-0.190	-0.109	-0.108	-0.518	0.042	-0.311	-0.293

Critical Value of r at 5% = .553

Table 19b: Correlation coefficients between SDS-sedimentation value, test weight, grain hardness, phenol reaction score, grain appearance score, gluten index, total proteins and total sugars under late sown conditions in MLHT I.

	SDS-Sedimentation Value	Test Weight	Grain Hardness	Phenol Reaction Score	Grain Appearance Score	Gluten Index	Protein Content
Test Weight	-0.164						
Grain Hardness	-0.581	0.382					
Phenol Reaction Score	0.145	0.310	0.262				
Grain Appearance Score	0.141	-0.169	-0.027	-0.200			
Gluten Index	-0.128	-0.338	-0.019	-0.262	-0.553		
Protein Content	0.750	-0.325	-0.774	-0.398	0.198	0.051	
Total Sugars	0.320	-0.532	-0.193	-0.104	0.544	0.021	0.345

Critical Value of r at 5% = .553

Table 20a: Correlation coefficients between SDS-sedimentation value, test weight, grain hardness, phenol reaction score, grain appearance score, gluten index, protein content and total sugars under timely sown conditions in MLHT II.

	SDS-Sedimentation Value	Test Weight	Grain Hardness	Phenol Reaction Score	Grain Appearance Score	Gluten Index	Protein Content
Test Weight	-0.040						
Grain Hardness	0.474	0.413					
Phenol Reaction Score	0.656	-0.029	.613				
Grain Appearance Score	-0.255	0.540	-.005	-0.402			
Gluten Index	-0.429	0.153	.085	-0.113	0.348		
Protein Content	0.598	0.234	.590	0.895	-0.326	-0.307	
Total Sugars	0.357	0.040	-.134	0.088	-0.507	-0.754	0.326

Critical Value of r at 5% = .576

Table 20b: Correlation coefficients between SDS-sedimentation value, test weight, grain hardness, phenol reaction score, grain appearance score, gluten index, protein content and total sugars under late sown conditions in MLHT II.

	SDS-Sedimentation Value	Test Weight	Grain Hardness	Phenol Reaction Score	Grain Appearance Score	Gluten Index	Protein Content
Test Weight	-0.029						
Grain Hardness	0.348	-0.005					
Phenol Reaction Score	-0.394	0.632	-0.515				
Grain Appearance Score	-0.256	0.726	-0.397	0.936			
Gluten Index	-0.336	0.564	-0.106	0.594	0.537		
Protein Content	0.154	-0.250	-0.296	-0.244	-0.303	-0.294	
Total Sugars	0.088	0.364	0.290	0.215	0.354	0.560	-0.286

Critical Value of r at 5% = .576

CHAPTER V

SUMMARY

The present study was aimed at studying the effect of early and late sowing of wheat (*Triticum aestivum* L.) under heat stress conditions on the antioxidant defense system and grain quality. It is one of the major staple food crop grown worldwide on more than 17% of the cultivatable land and produced in a wide range of climatic environments systems. It provides more than 50 percent of the total calories and 60 percent of the total proteins. April 2014, the United States Department of Agriculture (USDA) estimates that the World Wheat Production 2013/14 will be 712.52 million metric tons, around 0.19 million tons less than the previous year projection. India is the second largest producer of the wheat after china with 25 million ha area and 70 million tones production on an average. The targeted Indian wheat production for the year 2030 is approximately 95 million tons. In Punjab it occupies the largest area of 3528 hectares among the cereals, with production of 17982 metric tons.

The material for the study for first experiment comprised of 50 genetically diverse wheat genotypes. The material was planted in simple 5*5 lattice design in experimental fields of Plant Breeding and Genetics under two dates of sowing i.e. timely sown (25 Nov.) and late sown (23 Dec) during the year 2011-12. The data were recorded for leaf chlorophyll, canopy temperature depression, days to heading, plant height, peduncle length, number of grains per spike, number of spikelets per spike, grain weight per spike, total biomass, grain yield and heat susceptibility index. The analysis of variance revealed highly significant differences among genotypes. It indicated that the genotypes used in the investigation were genetically diverse. Significant interaction of genotypes with dates of sowing for all the traits studied suggested the differential response to heat stress and a need for identification of a separate set of genotypes for timely and late sown conditions.

Genotypes such as GW 431, RW 3705 and WH 1124 from MLHT I and genotypes HI 1571 and HD 3040 from MHT II had increased grain weight and grain number and spike number and hence showed tolerance behavior under heat stress. Genotypes HI 8703 and RAJ 4250 had decreased grain wt and grain number and spike number and hence were found to be susceptible under heat stress. High yielding genotypes were DBW 90, HD 3096, HD 2932, HI 8703, HUW 234, NW 2036, PBW 639, UAS 320 and WH 1123 under timely sown conditions and genotypes viz. DBW 90, HD 2932, HD 3040, HD 3090, HI 1563, HI 1571, HI 8703, GW 432, NW 2036, PBW 639, UAS 320 and WH 1124 were high yielding under late sown conditions.

Genotypes such as GW 433, HD 3090, MP 3353 and WH 1124 from MLHT I and HD 3040, HI 8703 and MP 3304 from MLHT II were found to be less susceptible to thermal

regimes that prevailed under late sown conditions. Lower values of heat susceptibility index for some genotypes indicated their better performance under late sown conditions. Genotypes HI 1571, PBW 670, RAJ 4250 and WH 1123 from MLHT I and HI 8703, PBW 639 and WHD 946 from MLHT II were found to be susceptible to high temperature due to higher values of heat susceptibility index. Total 25 genotypes (tolerant, susceptible and checks) from both trials MLHT I and MLHT II were selected for further biochemical and quality evaluation.

This selected material was used to study antioxidant enzymes such as catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), peroxidase (POX) and glutathione reductase (GR) and content of H₂O₂ and MDA and quality parameters such as grain appearance score, test weight, grain hardness, protein content, SDS-sedimentation value, phenol reaction score, grain plumpness, gluten content, gluten index, total sugars and starch pasting characteristics.

Genotypes such as WH 1124, HD 3040, HI 8703, MP 3304, DWB 14, HUW 234, MP 1040 and NW2036 had higher SOD activity under late sown conditions and were found to be tolerant under heat stress. Genotypes such as HD 3040, GW 433, HD 3090, MP 3353, WH 1124, RAJ 4250, WH 1123, HD 2864, RW 3705, RW 3765 and UAS 320 had higher POX activity under late sown conditions and were more tolerant to heat stress. All the genotypes had higher GR activity under timely sown conditions except genotypes HD 3040 and HI 8704. Genotypes MP 3353, WH 1124, HI 1571, PBW 670, RAJ 4250, WH 1123, HI 8703, HI 8704, PBW 639, WHD 946, DBW 14, MP 1040 and NW 2036 had higher APX activity under late sown conditions. Genotypes such as WH 1124, PBW 670, UAS 320, HD 3040, HI 8703, HI 8704, HUW 234 and PBW 373 had higher CAT activity under late sown conditions. Genotypes such as RAJ 3765, HD 3040, WHD 946 and HUW 234 had higher H₂O₂ content under late sown conditions. All the genotypes had high MDA content under late sown conditions.

Overall, the genotype WH 1124 from MLHT I had increased activity of enzymes superoxide dismutase, peroxidase, ascorbate peroxidase and catalase indicated better antioxidant defense system against heat stress and hence found to be the best among the selected tolerant genotypes. Genotype HD 3040 from MLHT II had increased activity of all antioxidative enzymes such as superoxide dismutase, peroxidase, glutathione reductase, ascorbate peroxidase and catalase showed tolerance against heat stress with enhanced activities of defense enzymes. HI 8703 from MLHT II was also found to be tolerant under heat stress with increased activities of antioxidant enzymes.

The grain appearance score, test weight, grain hardness, phenol reaction score, grain plumpness, gluten index found to be decreased under late sown conditions whereas proteins, SDS-Sedimentation value, sugars had found to be increased under heat stress conditions (late sown). Gluten content and starch pasting characteristics had not much affected by heat stress.

In MLHT I trial, genotype GW 433 and HD 3090 had increased grain appearance score, test weight, grain hardness, protein content, SDS-sedimentation value, grain plumpness, total sugars, dry gluten content and better starch pasting characteristics under late sown conditions and hence have better grain quality even under stress conditions. Genotype WH 1124 had better grain hardness, protein content, SDS-sedimentation value, grain plumpness, gluten content and quality, total sugars under late sown conditions, hence produce grains of better quality.

In MLHT II trial, genotype HD 3040 and HI 8703 had higher test weight, grain hardness, protein content, SDS-sedimentation value, grain plumpness, gluten content, total sugars and starch pasting characteristics under late sown conditions and hence showed tolerant behaviour under heat stress

Correlation studies revealed that protein positively correlate with SDS-sedimentation value, phenol reaction score, grain appearance score and hardness under timely sown conditions In MLHT trial, Proteins positively correlate with SDS- Sedimentation value and Gluten index shows negative correlation with grain appearance score under late sown conditions. In MLHT II, Grain appearance score, test weight and phenol reaction score were positively correlated with each other under late sown conditions.

WH 1124, HD 3090, GW 433 and HD 3040, HI 8703 from the trials MLHT I and MLHT II were the genotypes with enhanced antioxidative defense system including enzymatic and non-enzymatic components and can produce high yield and better quality grains under heat stress environment, hence identified as heat tolerant and better grain quality genotypes.

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Appendix I: Weekly maximum and minimum temperature during *rabi* season 2011-12.



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