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Review Article

Study of Terminal Heat Stress Effect in Yield and Yield Attributing Characters of Wheat: A Review

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Abstract

Wheat is an important staple food of world. Terminal heat stress is a major factor limiting wheat production in world. Reproductive stage of wheat is very sensitive to terminal heat stress. High temperature reduces days to booting, days to heading, days to anthesis, days to maturity, chlorophyll content, plant height, thousand kernel weight, spike per m^2, number of spikelets per spike, spike length, spike weight, number of grains per spike and grain yield. Heat stress causes alternation in physiological, biochemical and molecular level of wheat plant. Photosynthesis is most effecting physiological process. High temperature causes disruption of thylakoid membranes and disintegration of photosynthetic pigments resulting poor photosynthetic activity. In heat stress condition ROS (Reactive Oxygen Species) is produced which is very reactive and toxic that causes damages to cells. Plant produces detoxifying enzymes and antioxidants to detoxify effect of ROS. Osmotic pressure of cell is altered during heat stress condition which is balanced by producing proline and sugars in cells. EF-Tu (elongation factor thermo unstable), sRNA (small RNA), Hsp (Heat shock protein), Hsf (Heat shock factor), protein kinase acts as responsible factor to control heat stress in molecular level.

Keywords: Heat stress; Physiology; Thousand kernel weight; Wheat.

Introduction

Wheat (*Triticum aestivum)* is an important cereal food crop of Gramineae family (Akter & Rafiqul Islam, 2017). It is world's most favored staple food and is nutritious, easy to store, transport and can be processed into various types of food (Poudel *et al*., 2017). In world, wheat is in first rank in terms of production (765.76 million tonnes) and production area (215.9 million hectare) and productivity of wheat in world is 3.54 tonnes/hectare (*FAOSTATA*, 2019). Until 2050, the world requires additional 198 million tonnes of wheat to meet future demand of wheat for which wheat production to be increased by 77% in developing countries (Sharma *et al*., 2015). The wheat is consumed as food by human and feed by livestock and it is consumed by 2.5 billion people all over the world (Poudel *et al*., 2020). Wheat is good source of starch (60-70%), protein (6-26%), fibers, minerals (2.1%), fat (2.1%) and vitamins (Kumar *et al*., 2011). Puri *et al*. (2020) reported temperature of world is increased by 0.18°C in every decade. With rise in 1°C temperature there will be reduction of wheat production by 3-4 tonnes (3-4%) (Wardlaw *et al*., 1989). In Nepal, wheat is the third most important cereal crop after rice and maize in terms of both area and production (MOALD, 2017).

Productivity of wheat is 2.85 Metric tonnes/ha which is far below than average productivity of world (Krishi Dayari, 2077). The causes of low production of wheat in Nepal are genotype, climate change, global warming (Poudel *et al*., 2020), lack of inputs and irrigation (Sharma *et al*., 2020), soil fertility degradation and biotic/abiotic stresses like drought, heat stress and various diseases (Upadhyay, 2017). Under heat stress condition yield of wheat is reduced by about 50% (Senapati *et al*., 2018).

In South Asia with majority being in Eastern Gangetic Plains, the threat of terminal heat stress in wheat crop is increasing as the cool temperature is shrinking (Joshi *et al*., 2007). Many researchers found that time of sowing effect wheat yield (Poudel *et al*., 2017; Poudel *et al*., 2020). The wheat suffers from terminal heat stress in late sown condition. Two major causes of late planting of wheat are late harvesting of previous rice crop and long gap from rice harvest to wheat planting (Hobbs & Giri, 1997). Heat stress is major factor affecting the rate of plant growth and development (Hall, 1992). Under heat stress condition, crop duration of wheat is shorten as compared to normal conditions (Fischer & Laing, 1976) as there are fewer days to accumulate assimilate during their life cycle and production of biomass is reduced (Qaseem *et al*., 2019). Heat stress effect during anthesis and reproductive stage is known as terminal heat stress. Reproductive stage of wheat is markedly affected by high temperature, which ultimately affect fertilization and post-fertilization process leading to reduced crop yield (Wahid *et al*., 2007). The optimum temperature of wheat for grain filling is 15-18℃ (Chowdhury & Wardlaw, 1978). High temperature during reproductive stage decreases grain filling duration and thousand kernel weight (Poudel *et al*., 2017). Growth and development of wheat is determined by temperature regime and physiological maturity, grain filling duration and wheat yield are affected by high temperature (Hossain *et al*., 2012). Heat stress affect plant water relations (Qaseem *et al*., 2019), reduce photosynthetic capacity (Subhani *et al*., 2010), decrease metabolic activities (Farooq *et al*., 2011), cause changes in hormones, production of oxidative reaction species (Wang *et al*., 2011), promotion of ethylene production (Hays *et al*., 2007), reduction of pollen tube development and increase of pollen mortality (Oshino *et al*., 2011). To escape from terminal heat stress, early maturing and fast grain filling wheat varieties should be selected (Mondal *et al*., 2013). There is need to develop high temperature tolerant wheat varieties with disease resistance and stay green traits which are capable of producing enough endosperm, bold grains within short grain filling duration to meet growing demand of food (Puri *et al*., 2020).

Heat Stress: A Focus Point

Wheat is considered as the one of the first cereal crop to be domesticated in world (Mollasadeghi & Shahryari, 2011) and is an important staple food (Dubcovsky & Dvorak, 2007). Wheat is good source of human protein which contain higher protein content as compared to rice and maize (Mollasadeghi & Shahryari, 2011). Grain yield of wheat is determined by various direct and indirect factors (Zampieri *et al*., 2017). The climatic factors such as temperature, rainfall, CO_2 and O_2 ratio and soil moisture condition would have both positive and negative effects on production of wheat (Joshi & Kar, 2009). Wheat is very sensitive to high temperature condition (Gupta *et al*., 2013). Heat stress is known as a great hindrance to successful crop production in the world (Kumari *et al*., 2007). Heat stress is defined as the rise in air temperature beyond the threshold level for a period of time sufficient to cause injury or irreversible damage to the crop plants (Teixeira *et al*., 2013). High temperature causes poor germination and plant establishment, poor photosynthesis, reduced bio-accumulation, leaf senescence, pollen sterility, reduction of grain weight and total grain yield (Nahar *et al*., 2010; Asseng *et al*., 2011; Al-Khatib & Paulsen, 1984).

Heat stress causes morphological, physiological and molecular alterations and reduces total grain yield (McClung & Davis, 2010). High temperature degenerates the mitochondria, changes the protein structures and reduces ATP accumulation (Balla *et al*., 2012). Under heat stress condition, water potential of wheat leaf decreases and eventually reduce photosynthetic productivity (Farooq *et al*., 2009). Transpiration and plant growth are severely affected by high temperature (Akter & Rafiqul, 2017). Nahar *et al*. (2010) reported that, rise in 1-2℃ temperature accelerates seed growth rate and shortened grain filling duration reducing seed mass. Reproductive stages of wheat such as gametogenesis (8-9 days before anthesis), booting and fertilization (1-3 days after anthesis) are detrimental to high temperature (Akter & Rafiqul, 2017).

Effect of Heat Stress in Yield and Yield Attributing Characters

A. Days to Booting

Number of days from sowing to 50% of the plants in a plot having swollen flag leaf sheath is known as days to booting (Poudel *et al*., 2020). In late sown condition, booting occurs in less time than in normal condition (Poudel *et al*., 2020; Nahar *et al*., 2010).

B. Days to Heading

Ali *et al*. (2020) and Hossain, Teixeira da Silva *et al*. (2012) reported heading is earlier in late sown condition than in normal sown condition. Poudel *et al*. (2020) found mean days to heading 13.65% higher in late sown condition.

C. Days to Anthesis

High temperature during anthesis can cause floret abortion (Wardlaw, 1994) and pollen sterility (Farooq *et al*., 2011).

Saini & Aspinall (1982) mentioned that the temperature above 30 °C during floret formation it can cause complete sterility. The reason for earlier heading under heat stress may be reduced heat units and low accumulated metabolites required for wheat flowering (Ali *et al*., 2020). High temperature during anthesis to grain maturity cause yield reduction because of reduced time to capture resources (Farooq *et al*., 2011).

D. Days to Maturity

Under heat stress condition rate of growth and development becomes high and days to maturity is reduced (Connor *et al*., 1992). Wheat sown in late condition has short physiological maturity period (Joshi & Singh, 1983). Hossain *et al*. (2017) also found early maturity in late sown wheat. Wheat sown in late has short physiological maturity period (Joshi & Singh, 1983).

E. Chlorophyll Content (SPAD)

Under heat stress condition, there is lower chlorophyll content than in normal environment condition (Rosyara *et al*., 2010). High temperature damages thylakoid membranes and enzymes involved in photosynthesis (Ristic *et al*., 2007). In high temperature biosynthesis of chlorophyll is less and degradation is high.

F. Plant Height

High temperature affects plant meristems and reduce plant growth causing leaf senescence and abscission and by reducing photosynthesis (Kosova *et al*., 2011). Plant grown in high temperature condition produce lower biomass compared to plants grown under normal condition (Akter & Rafiqul Islam, 2017).

G. Thousand Kernel Weight

Thousand kernel weight in late sown condition is lower than in normal sown condition (Akhtar *et al*., 2006; Adam & Jahan, 2019). Heat stress in the post anthesis period reduces duration of grain filling thus reducing thousand kernel weight (Wiegand & Cuellar, 1981). Connor *et al*. (1992) reported high rate of transpiration and respiration under heat stress condition thus affecting photosynthetic assimilation.

I. Spike/m²

Spike per m^2 is define as productive tillers formed in the period starting from the initial seedling stage (fourth leaf stage) to the end of the vegetative growth (pre-booting stage) (Abdelrahman *et al*., 2020). Joshi & Singh (1983) found lesser number of spikes per meter square in late sown condition than in normal sown condition. The result for this may be due to unfavorable temperature condition for photosynthetic accumulation and growth (Farooq *et al*., 2011).

J. Number of Spikelet Per Spike

Under heat stress condition, less number of spikelet per spike is observed in late sown condition than normal sown condition (Hossain *et al*., 2017).

K. Number of Grains Per Spike

Tahir *et al*. (2009) and Poudel *et al*. (2020) found lower value of mean number of grains per spike in late sown wheat. Decrease in number of grains per spike is due to decrease in photosynthetic production in shorter growing period (Baloch *et al*., 2012).

L. Spike Length

Spike length of wheat is reduced under heat stress condition (Shahzad *et al*., 2002). Shah *et al*. (2006) also found decrease in spike length with delay in sowing time. Poudel *et al*. (2020) found mean spike length 4.48% higher in normal sown condition than in late sown condition.

M. Spike Weight

Spike weight in late sown condition is lower than in normal sown condition (Poudel *et al*., 2020). The cause of low spike weight is due to poor grain development and poor grain filling under heat stress condition.

N. Weight of Grains Per Spike

Khokhar *et al*. (2010) and Ercoli *et al*. (2009) reported that increasing temperature during period from anthesis to maturity reduce weight of grains per spike. Poudel *et al*. (2020) found 18.07% higher mean weight of grains per spike than in late sown condition.

O. Grain Yield

Heat stress during grain formation stage leads to abnormal shriveled grain and low production of grain (Baloch *et al*., 2012). Heat stress causes reduction of kernel density and weight by up to 7% in spring wheat (Guilioni *et al*., 2003). Asana & Williams (1947) found that increase in each degree of temperature during grain filling period causes reduction of about three days in the duration of grain filling. Ali *et al*. (2020) and Senapati *et al*. (2018) reported that higher yield in normal sown condition is due to maximum number of tillers per square area, more number of grains per spike, more weight of grains per spike and favorable solar condition.

Physiological Response

Photosynthesis is most sensitive physiological event affected by high temperature (Feng *et al*., 2014). Photosystem II is much sensitive to heat stress than photosystem I (Marutani *et al*., 2012). High temperature damages chloroplast and chlorophyll content is reduced that result in poor photosynthesis activity (Keyvan, 2010). High temperature causes disruption of thylakoid membranes and inhibits membrane-associated electron carriers and enzymes that ultimately results in reduced rate of photosynthesis (Ristic *et al*., 2008). Under heat stress condition, oxidative stress induced that inactivates chloroplast enzymes and reduced net photosynthesis capacity (Ainsworth & Ort, 2010). There is changes in structure of chloroplast by changing shape, swelling of stromal lamellae and clumping of vacuoles thus chlorophyll content reduced (Ristic *et al*., 2007; Ristic *et al*., 2008). High temperature causes disintegration of chlorophyll molecules and also cause damage to the photosynthetic apparatus (Qaseem *et al*., 2019). Above 40°C temperature, there is permanent alteration of Rubisco and Rubisco activase enzymes (Mathur *et al*., 2011). Rubisco activase break down upon heat stress condition and photosynthesis activity is reduced (Raines, 2011). High temperature during grain formation period effect source- link relationship (Abdelrahman *et al*., 2020) that results in poor assimilation of photosynthates in grain (Talukder *et al*., 2014). Grain weight is determined by the duration and rate of grain filling and under heat stress condition grain filling rate is increased and duration of grain filling is reduced (Girousse *et al*., 2018). Under heat stress condition water content reduced and photorespiration occurs due to closure of stomata (McCord, 2000). Dehydration of plant tissue occurs due to high temperature and restricts plant growth and development (Akter & Rafiqul Islam, 2017). In high temperature reactive oxygen species (ROS) is generated in chloroplast, mitochondria and peroxisome which effect normal metabolism through oxidative damage of lipids, proteins and nucleic acids (McCord, 2000).

Biochemical Response

Under heat stress condition there are various biochemical changes within plant cells. Osmotic stress under heat stress condition causes synthesis and catabolism of several other growth regulators including auxin, cytokinins, ethylene and other factors (N and pH) (Verma *et al*., 2016). During heat stress condition, plant maintains osmotic pressure of cytosol with vacuole and external environment and by producing compatible solutes such as proline protein and sugar (Moinuddin & Goswami, 2004) this protects the cells from injury and maintains turgor pressure (Ashraf & Foolad, 2007; Abdel-Motagally & El-Zohri, 2018). Among amino acid, proline has played major role in maintaining osmotic pressure of cell in heat stress condition (Zandalinas *et al*., 2017). Level of intracellular Ca^{2+} increased during heat stress condition as a result of effect of several signal molecules such as inositol triphosphate, inositol hexaphosphate, diacylglycerol and ROS (Hirayama & Shinozaki, 2010). Then Ca^{2+} sensors (calcium binding proteins) leads to activation of calcium dependent protein kinase and phosphorylation and de-phosphorylation of specific transcription factors occurs which regulate the expression levels of stress responsive genes (Reddy *et al*., 2011). Reddy *et al*. (2011) also mentioned activated Ca^{2+} sensors bind to cis-elements and DNA-binding proteins that cause activation and suppression of functions of regulating genes.

Heat stress causes protein denaturation, instabilities in nucleic acids, increased membrane fluidity, inactivation of synthesis and degradation of proteins and loss of membrane integrity (Wahid *et al*., 2007). Severe heat stress causes cellular loss and injury depending on period of exposure to high temperature (Wahid *et al*., 2007). Under heat stress condition, ROS (reactive oxygen species) is produced which are extremely reactive and toxic and causes damage to proteins, lipids, carbohydrates and DNA which is known as oxidative stress (Zlatev & Cebola, 2012). In plant, oxidative stress is neutralized by induction of detoxifying enzymes and antioxidants such as ascorbate peroxidase, peroxidase, superoxidase dismutase, catalase, glutathione peroxidases and glutathione reductase (Gill & Tuteja, 2010). Yadav *et al*. (2005) found that there is also production of two-to-six-fold higher methylglyoxal under heat stress condition which is very reactive and cytotoxic. Methylglyoxal is responsible for damaging cellular function and also can cause damages to DNA (Hasanuzzaman *et al*., 2017). Under heat stress condition, wide range of metabolites of low molecular mass such as glucose, fructose, amino acids and alcohols are produced which assistant to prevent detrimental changes in cellular components (Vinocur & Altman, 2005).

Molecular Response

Various molecular mechanisms are taken place to adapt during heat stress condition. Synthesis of heat stress (HS) proteins involved at molecular level that helps plant to cope with heat stress (Jemaa, 2010). High temperature causes changes of signal's perception at molecular level altering the expression of genes and accumulation of transcripts leading to synthesis of stress related proteins as a tolerance strategy (Iba, 2002). Heat stress generate oxidative stress in cell by producing reactive oxygen species (ROS) in the form of singlet oxygen (O_2), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH^-) (Jemaa, 2010). ROS causes injury to cell membrane and proteins (Mittler & Blumwald, 2015). To detoxify the effects of ROS cell produce ROS scavenging enzymes such as superoxidase dismutase (SOD), peroxidase (POD), catalase (CTA), glutathione peroxidases (GPX), glutathione reductase (GR) at cellular level (Iba, 2002). ROS scavenging mechanism have an important role in protecting plants against temperature stresses (Iba, 2002). Protein synthesis elongation factor (EF-Tu) in chloroplast is increased during heat stress condition which is associated with heat tolerance in wheat (Fu *et al*., 2012). EF-Tu helps to protect leaf protein from thermal aggregation, reduces thylakoid membrane destruction which enhances photosynthetic capability(Fu *et al*., 2012). More EF-Tu contents in wheat genotype shows more tolerance to heat stress (Ristic *et al*., 2008). Small

RNA(sRNA) derived from tRNA, rRNA and snoRNA plays an important role during heat stress(Fu *et al*., 2012). 333 st RNA and 88222 srRNA is more responsible to heat stress(Fu *et al*., 2012).Protein kinase and transcription acts as major factor and heat shock protein (Hsp) and catalase (CAT) acts as functional gene to control heat stress (Todaka *et al*., 2012). HsfA1a acts as master regulator (Mishra *et al*., 2002; Baniwal *et al*., 2004) and HsfA2 acts as major heat stress factor in plant to control heat stress (Kotak *et al*., 2007).

Conclusion

Heat stress during pre-anthesis and grain filling duration is detrimental in wheat production. Heat stress causes various physiological, biochemical, and molecular alterations in wheat plant. Yield of wheat is reduced under heat stress condition. The reasons behind it may be poor performance of wheat plant under heat stress condition. Photosynthesis is main physiological process effected by high temperature. High temperature damages photosystems, photosynthetic pigments, electron transport system and CO_2 reduction pathway and reduce photosynthesis activity leading poor grain production. The plant breeders should focus on the development of heat stress tolerant wheat varieties that are capable to produce high yield under heat stress condition.

Reference

Abdel-Motagally FMF and El-Zohri M (2018) Improvement of wheat yield grown under drought stress by boron foliar application at different growth stages. *Journal of the Saudi Society of Agricultural Sciences*. **17**: 178–185. https://doi.org/10.1016/j.jssas.2016.03.005

Abdelrahman M, Burritt D J, Gupta A, Tsujimoto H, and Tran LSP (2020) Heat stress effects on source-sink relationships and metabolome dynamics in wheat. *Journal of Experimental Botany*. **71**: 543–554. https://doi.org/10.1093/jxb/erz296

Adam AG &and Jahan N (2019) Effects of sowing time on growth and yield performance of six high yielding varieties of wheat (*Triticum Aestivum* L.). *Bangladesh Journal of Botany*, **48**: 43–51. https://doi.org/10.3329/bjb.v48i1.47415

Ainsworth EA and Ort DR (2010) How do we improve crop production in a warming world? *Plant Physiology*. **158**: 526–530. https://doi.org/10.1104/pp.110.161349

Akhtar M, Cheema MS, Jamil M and Ali L (2006) Effect of Time Of Sowing on Some Important Characters of Wheat, *Triticum aestivum* Genotypes. *Journal of Agricultural Research (Pakistan)*. **44**: 255–259.

Akter N and Rafiqul Islam M (2017) Heat stress effects and management in wheat: A review. *Agronomy for Sustainable Development*, **37**: 1–6. https://doi.org/10.1007/s13593-017-0443-9

Al-Khatib K and Paulsen GM (1984). Mode of high temperature injury to wheat during grain development. *Physiologia Plantarum*. **61**: 363–368. https://doi.org/10.1111/j.1399-3054.1984.tb06341.x

Ali M, Hassan MS, Ahmed HMA and Zakaria MM (2020) Wheat Research Institute, Agriculture Reseach Center, Giza, Egypt. *International Journal of Agricultural Science*, **2**: 451–466.

Asana RD and Williams RF (1965) The effect of temperature stress on grain development in wheat. *Aust. J. Agric. Res*, **16**: 1-13

Ashraf M and Foolad MR (2007) Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and Experimental Botany*, **59**: 206–216. https://doi.org/10.1016/j.envexpbot.2005.12.006

Asseng S, Foster I and Turner NC (2011). The impact of temperature variability on wheat yields. *Global Change Biology*, **17**: 997–1012. https://doi.org/10.1111/j.1365-2486.2010.02262.x

Balla K, Karsai I, Bencze S and Veisz O (2012) Germination ability and seedling vigour in the progeny of heat-stressed wheat plants. *Acta Agronomica Hungarica*, **60**: 299–308. https://doi.org/10.1556/AAgr.60.2012.4.1

Baloch MS, Nadim MA, Zubair M, Awan IU, Khan EA and Ali S (2012) Evaluation of wheat under normal and late sowing conditions. *Pakistan Journal of Botany*, 44: 1727–1732.

Baniwal SK, Bharti K, Chan KY, Fauth M, Ganguli A, Kotak S, Mishra SK, Nover L, Port M, Scharf KD, Tripp J, Weber C and Zielinski D (2004) Heat stress response in plants: A complex game with chaperones and more than twenty heat stress transcription factors. *Journal of Biosciences*, **29**: 471–487. https://doi.org/10.1007/BF02712120

Chowdhury SI and Wardlaw IF (1978) The effect of temperature on kernel development in cereals. *Australian Journal of Agricultural Research*, **29**: 205–223. https://doi.org/10.1071/AR9780205

Connor DJ, Theiveyanathan S and Rimmington GM (1992) Development, growth, water-use and yield of a spring and a winter wheat in response to time of sowing. *Australian Journal of Agricultural Research*, **43**: 493–516. https://doi.org/10.1071/AR9920493

Dubcovsky J and Dvorak J (2007) Genome plasticity a key factor in the success of polyploid wheat under domestication. *Science*, **316**: 1862–1866. https://doi.org/10.1126/science.1143986

Ercoli L, Masoni A, Mariotti M and Arduini I (2009) Accumulation of Dry Matter and Nitrogen in Durum Wheat During Grain Filling as Affected by Temperature and Nitrogen Rate. *Italian Journal of Agronomy*, **4**: 3–13. https://doi.org/10.4081/ija.2009.1.3

FAOSTATA. (2019).

Farooq M, Wahid A, Kobayashi N, Fujita D and Basra SMA (2009) Review article Plant drought stress : effects, mechanisms and management. *Agron. Sustain. Dev*, **29**: 185–212.

Farooq M, Bramley H, Palta JA and Siddique KHM (2011) Heat stress in wheat during reproductive and grain-filling phases. *Critical Reviews in Plant Sciences*, **30**: 491–507. https://doi.org/10.1080/07352689.2011.615687

Feng B, Liu P, Li G, Dong ST, Wang FH, Kong LA and Zhang JW (2014) Effect of Heat Stress on the Photosynthetic Characteristics in Flag Leaves at the Grain-Filling Stage of Different Heat-Resistant Winter Wheat Varieties. *Journal of Agronomy and Crop Science*, **200**: 143–155. https://doi.org/10.1111/jac.12045

Fischer RA and Laing DR (1976) Yield potential in a dwarf spring wheat and response to crop thinning. *The Journal of Agricultural Science*, **87**: 113–122. https://doi.org/10.1017/S0021859600026654

Fu J, Momclovic I and Prasad V (2012) Molecular bases and improvement of heattoleranceincrop plants. *Nova Science*, 185–214.

Gill SS and Tuteja N (2010) Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry* **48**: 909–930. https://doi.org/10.1016/j.plaphy.2010.08.016

Girousse C, Roche J, Guerin C, Le Gouis J, Balzegue S, Mouzeyar S and Bouzidi MF (2018) Coexpression network and phenotypic analysis identify metabolic pathways associated with the effect of warming on grain yield components in wheat. *PLoS ONE*, **13**: 1-24 https://doi.org/10.1371/journal.pone.0199434

Guilioni L, Wéry J and Lecoeur J (2003) High temperature and water deficit may reduce seed number in field pea purely by decreasing plant growth rate. *Functional Plant Biology*, **30**: 1151–1164. https://doi.org/10.1071/FP03105

Gupta K, Dey A and Gupta B (2013) Plant polyamines in abiotic stress responses. *Acta Physiologiae Plantarum*, **35**: 2015–2036. https://doi.org/10.1007/s11738-013-1239-4

Hall A (1992) Breeding for Heat Tolerance. *Offprints from Plant Breeding Reviews,* **10**: 129-168.

Hasanuzzaman M, Nahar K, Hossain MS, Mahmud JA, Rahman A, Inafuku M, Oku H and Fujita M (2017) Coordinated actions of glyoxalase and antioxidant defense systems in conferring abiotic stress tolerance in plants. *International Journal of Molecular Sciences*, **18** https://doi.org/10.3390/ijms18010200

Hays DB, Do JH, Mason RE, Morgan G and Finlayson SA (2007) Heat stress induced ethylene production in developing wheat grains induces kernel abortion and increased maturation in a susceptible cultivar. *Plant Science*, **172**: 1113–1123. https://doi.org/10.1016/j.plantsci.2007.03.004

Hirayama T and Shinozaki K (2010) Research on plant abiotic stress responses in the post-genome era: Past, present and future. *Plant Journal*, **61**: 1041–1052. https://doi.org/10.1111/j.1365-313X.2010.04124.x

Hobbs PR and Giri GS (1997) Reduced and zero-tillage options for establishment of wheat after rice in South Asia. 455–465. https://doi.org/10.1007/978-94-011-4896-2_60

Hossain A, Islam MR, Rahman KAMM, Rashid MH and Anwari A (2017). Comparative performance of three wheat (*Triticum aestivum* L.) varieties under heat stress. *International Journal of Natural and Social Sciences*, **4**: 16–24.

Hossain A, Teixeira da Silva JA. Lozovskaya MV and Zvolinsky VP (2012) High temperature combined with drought affect rainfed spring wheat and barley in South-Eastern Russia: I. Phenology and growth. *Saudi Journal of Biological Sciences*, **19**: 473–487. https://doi.org/10.1016/j.sjbs.2012.07.005

Iba K (2002) Acclimative Responsive to Temperatures Trees in Higher Plants : Approaches of Gene Engineering for Temperature Tolerance. *Annu. Rev. Plant Biol*, **53**: 225–245. https://doi.org/10.1146/annurev.arplant.53.100201.160729

Jemaa E (2010) Impact of Heat Stress on Germination and Growth in Higher Plants : Physiological , Biochemical and Molecular Repercussions and Mechanisms of Defence. *Journal of Biological Sciences*, **10**: 565–572. https://doi.org/10.3923/jbs.2010.565.572

Joshi AK, Mishra B, Chatrath R, Ortiz Ferrara G and Singh RP (2007) Wheat improvement in India: Present status, emerging challenges and future prospects. *Euphytica*, **157**: 431–446. https://doi.org/10.1007/s10681-007-9385-7

Joshi NL and Kar A (2009) Contingency crop planning for dryland areas in relation to climate change. *Indian Journal of Agronomy*, **54**: 237–243.

Joshi N and Singh H (1983) Performance of Wheat Varieties Under Different Sowing Dates on Semi Arid-lands. *Indian Journal of Agronomy*, **28**: 54–58.

Keyvan S (2010) The effects of drought stress on yield, relative water content, proline, soluble carbohydrates and chlorophyll of bread wheat cultivars. *Journal of Animal & Plant Sciences*, **8**: 1051–1060. http://www.biosciences.elewa.org/JAPS;

Khokhar Z, Hussain I, Khokhar B and Sohail M (2010) Effect Of Planting Date On Yield Of Wheat Genotypes In Sindh. *Pakistan J. Agric. Res.*, **3**: 103–107.

Kosova K, Vitamvas P, Prasil IT and Renaut J (2011) Plant proteome changes under abiotic stress - Contribution of proteomics studies to understanding plant stress response. *Journal of Proteomics*, **74**: 1301–1322. https://doi.org/10.1016/j.jprot.2011.02.006

Kotak S, Larkindale J, Lee U, Von Koskull-Döring P, Vierling E and Scharf KD (2007) Complexity of the heat stress response in plants. *Current Opinion in Plant Biology*, **10**: 310–316. https://doi.org/10.1016/j.pbi.2007.04.011

Krishi Dayari 2077 (2077) Krishi Tatha Pashupanchi Mantralaya.

Kumar P, Yadava R, Gollen B, Kumar S, Verma R and Yadav S (2011) Nutritional Contents and Medicinal Properties of Wheat: A Review. *Life Sciences and Medicine Research*, 2011: 22.

Kumari M, Singh VP, Tripathi R and Joshi AK (2007) Variation for Staygreen Trait and its Association with Canopy Temperature Depression and Yield Traits Under Terminal Heat Stress in Wheat. *International Journal of Plant Breeding,* 357–363. https://doi.org/10.1007/1-4020-5497-1_44

Marutani Y, Yamauchi Y, Kimura Y, Mizutani M and Sugimoto Y (2012) Damage to photosystem II due to heat stress without light-driven electron flow: Involvement of enhanced introduction of reducing power into thylakoid membranes. *Planta*, **236**: 753–761. https://doi.org/10.1007/s00425-012-1647-5

Mathur S, Jajoo A, Mehta P and Bharti S (2011) Analysis of elevated temperature-induced inhibition of photosystem II using chlorophyll a fluorescence induction kinetics in wheat leaves (*Triticum aestivum*). *Plant Biology*, **13**: 1–6. https://doi.org/10.1111/j.1438-8677.2009.00319.x

McClung CR and Davis SJ (2010) Ambient thermometers in plants: From physiological outputs towards mechanisms of thermal sensing. *Current Biology*, **20**: 1086–1092. https://doi.org/10.1016/j.cub.2010.10.035

McCord JM (2000) The evolution of free radicals and oxidative stress. *American Journal of Medicine*, **108**: 652–659. https://doi.org/10.1016/S0002-9343(00)00412-5

Mishra SK, Tripp J, Winkelhaus S, Tschiersch B, Theres K, Nover L and Scharf KD (2002) In the complex family of heat stress transcription factors, HsfA1 has a unique role as master regulator of thermotolerance in tomato. *Genes and Development*, **16**: 1555–1567. https://doi.org/10.1101/gad.228802

Mittler R and Blumwald E (2015) The Roles of ROS and ABA in Systemic Acquired Acclimation. *American Society of Plant Biologists*, **27**: 64–70. https://doi.org/10.1105/tpc.114.133090

MOALD (2017) Statistical Information in Nepalese Agriculture. *Ministry of Agriculture and Livestock*, 290. https://nepalindata.com/resource/statistical-information-nepalese-agriculture-207374-201617/

Moinuddin G and Goswami S (2004) Response Of Wheat To Water Deficit And Foliar Spray Of Urea And Potassium Sulphate. *Indian Journal of Plant Physiology*, **9**: 212–215.

Mollasadeghi V and Shahryari R (2011) Important morphological markers for improvement of yield in bread wheat. *Advances in Environmental Biology*, **5**: 538–542.

Mondal S, Singh RP, Crossa J, Huerta-Espino J, Sharma I, Chatrath R, Singh GP, Sohu VS, Mavi GS, Sukaru VSP, Kalappanavarg IK, Mishra VK, Hussain M, Gautam NR, Uddin J, Barma NCD, Hakim A and Joshi AK (2013) Earliness in wheat: A key to adaptation under terminal and continual high temperature stress in South Asia. *Field Crops Research*, **151**: 19–26. https://doi.org/10.1016/j.fcr.2013.06.015

Nahar K, Ahamed KU and Fujita M (2010) Phenological Variation and its Relation with Yield in several Wheat (*Triticum aestivum* L .) Cultivars under Normal and Late Sowing Mediated Heat Stress Condition. *Not Sci Biol*, **2**: 51–56.

Oshino T, Miura S, Kikuchi S, Hamada K, Yano K, Watanabe M and Higashitani A (2011) Auxin depletion in barley plants under high-temperature conditions represses DNA proliferation in organelles and nuclei via transcriptional alterations. *Plant, Cell and Environment*, **34**: 284–290. https://doi.org/10.1111/j.1365-3040.2010.02242.x

Poudel A, Thapa DB and Sapkota M (2017) Cluster Analysis of Wheat (*Triticum aestivum* L.) Genotypes Based Upon Response to Terminal Heat Stress. *International Journal of Applied Sciences and Biotechnology*, **5**: 188–193. https://doi.org/10.3126/ijasbt.v5i2.17614

Poudel MR, Ghimire S, Pandey MP, Dhakal K, Thapa DB and Poudel HK (2020) Yield Stability Analysis of Wheat Genotypes at Irrigated, Heat Stress and Drought Condition. *Journal of Biology and Today's World*, **9**: 220.

Poudel PB, Jaishi UK, Poudel L and Poudel MR (2020) Evaluation of Wheat Genotypes under Timely and Late Sowing Conditions. *International Journal of Applied Sciences and Biotechnology*, **8**: 161–169. https://doi.org/10.3126/ijasbt.v8i2.29593

Puri RR, Tripathi S, Bhattarai R, Dangi SR and Pandey D (2020) Wheat Variety Improvement for Climate Resilience. *Asian Journal of Research in Agriculture and Forestry*, **6**: 21–27. https://doi.org/10.9734/ajraf/2020/v6i230101

Qaseem MF, Qureshi R and Shaheen H (2019) Effects of Pre-Anthesis Drought, Heat and Their Combination on the Growth, Yield and Physiology of diverse Wheat (*Triticum aestivum* L.) Genotypes Varying in Sensitivity to Heat and drought stress. *Scientific Reports*, **9**: 1–12. https://doi.org/10.1038/s41598-019-43477-z

Raines CA (2011) Increasing photosynthetic carbon assimilation in C3 plants to improve crop yield: Current and future strategies. *Plant Physiology*, **155**: 36–42. https://doi.org/10.1104/pp.110.168559

Reddy ASN, Ali GS, Celesnik H and Day IS (2011) Coping with stresses: Roles of calcium- and calcium/calmodulin-regulated gene expression. *Plant Cell*, **23**: 2010–2032. https://doi.org/10.1105/tpc.111.084988

Ristic Z, Bukovnik U, Momčilović I, Fu J and Vara Prasad PV (2008) Heat-induced accumulation of chloroplast protein synthesis elongation factor, EF-Tu, in winter wheat. *Journal of Plant Physiology*, **156**: 192–202. https://doi.org/10.1016/j.jplph.2007.03.003

Ristic Z, Bukovnik U and Prasad PVV (2007) Correlation between heat stability of thylakoid membranes and loss of chlorophyll in winter wheat under heat stress. *Crop Science*, **47**: 2067–2073. https://doi.org/10.2135/cropsci2006.10.0674

Rosyara U, Subedi S, Duveiller E and Sharma (2010) Photochemical Efficiency and SPAD Value as Indirect Selection Criteria for Combined Selection of Spot Blotch and Terminal Heat Stress in Wheat. *Journal of Phytopathology*, **158**: 813–821. https://doi.org/10.1111/j.1439-0434.2010.01703.x

Saini HS and Aspinall D (1982) Abnormal sporogenesis in wheat

(Triticum aestivum L.) induced by short periods of high temperature. *Annals of Botany*, **49**: 835–846. https://doi.org/10.1093/oxfordjournals.aob.a086310

Senapati N, Matthew PS, Paul J and Semenov MA (2018) Drought tolerance during reproductive development is important for increasing wheat yield potential under climate change in Europe. *Journal of Experimental Botany*, **70**: 2549–2560. https://doi.org/10.1093/jxb/ery226/5036557

Shah WA, Bakht J, Ullah T, Khan AW, Zubair M Khakwani AA (2006) Effect of sowing dates on the yield and yield components of different wheat varieties. In *Journal of Agronomy* **5**: 106–110 https://doi.org/10.3923/ja.2006.106.110

Shahzad K, J. B. WAS, M. S and N. J (2002) Yield and Yield Components of Various Wheat Cultivars as Affected by Different Sowing Dates. *Asian Journal of Plant Sciences*, **1**: 522–525. https://doi.org/10.3923/ajps.2002.522.525

Sharma H, Chapagain S and Marasini S (2020) Impact of climate change on paddy-wheat production and the local adaptation practices by farmers of. *International Journal of Agriculture, Forestry and Life Sciences*, **4**: 137–146.

Sharma I, Tyagi BS, Singh G, Venkatesh K and Gupta OP (2015) Enhancing wheat production - A global perspective. *Indian Journal of Agricultural Sciences*, **85**: 3–13.

Subhani GM, Ahmad N, Hussain M, Rehman AU and Riaz-ud-Din (2010) Effect of temperature on development and grain formation in spring wheat. *Pakistan Journal of Botany*, **42**: 899–906.

Tahir M, Ali A, Nadeem MA, Hussain A and Khalid F (2009) Effect of different sowing dates on growth and yield of wheat (*Triticum aestivum* L.) varieties in District Jhang, Pakistan. *Pakistan Journal of Life and Social Science*, **7**: 66–69.

Talukder ASMHM, McDonald GK and Gill GS (2014) Effect of short-term heat stress prior to flowering and early grain set on the grain yield of wheat. *Field Crops Research*, **160**: 54–63. https://doi.org/10.1016/j.fcr.2014.01.013

Teixeira EI, Fischer G, Van Velthuizen H, Walter C and Ewert F (2013) Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology*, **170**: 206–215. https://doi.org/10.1016/j.agrformet.2011.09.002

Todaka D, Nakashima K, Shinozaki K and Yamaguchi-Shinozaki, K. (2012). Toward understanding transcriptional regulatory networks in abiotic stress responses and tolerance in rice. *Rice*, **5**: 1–9. https://doi.org/10.1186/1939-8433-5-6

Upadhyay SR (2017) Wheat Research and Development Present Status and Future Strategies in Nepal. *Proceedings of 30th National Winter Crops Workshop*. Government of Nepal Nepal Agricultural Research Council.

Verma V, Ravindran P and Kumar PP (2016) Plant hormone-mediated regulation of stress responses. *BMC Plant Biology*, **16**: 1–10. https://doi.org/10.1186/s12870-016-0771-y

Vinocur B and Altman A (2005) Recent advances in engineering plant tolerance to abiotic stress: Achievements and limitations. *Current Opinion in Biotechnology*, **16**: 123–132. https://doi.org/10.1016/j.copbio.2005.02.001

Wahid A, Gelani S, Ashraf M and Foolad MR (2007) Heat tolerance in plants: An overview. *Environmental and Experimental Botany*, **61**: 199–223. https://doi.org/10.1016/j.envexpbot.2007.05.011

Wang X, Cai J, Jiang D, Liu F, Dai T and Cao W (2011) Pre-anthesis high-temperature acclimation alleviates damage to the flag leaf caused by post-anthesis heat stress in wheat. *Journal of Plant Physiology*, **168**: 585–593. https://doi.org/10.1016/j.jplph.2010.09.016

Wardlaw I (1994) The Effect of High Temperature on Kernel Development in Wheat: Variability Related to Pre-Heading and Post-Anthesis Conditions. *Functional Plant Biology*, **21**: 731. https://doi.org/10.1071/pp9940731

Wardlaw IF, Dawson IA, Munibi P and Fewster R (1989) The tolerance of wheat to high temperatures during reproductive growth. I. Survey procedures and general response patterns. *Australian Journal of Agricultural Research*, **40**: 1–13. https://doi.org/10.1071/AR9890001

Wiegand CL and Cuellar JA (1981) Duration of Grain Filling and Kernel Weight of Wheat as Affected by Temparature1. *Crop Science*, **21**: 95. https://doi.org/10.2135/cropsci1981.0011183x001100010027x

Yadav SK, Singla-Pareek SL, Ray M, Reddy MK and Sopory SK (2005) Methylglyoxal levels in plants under salinity stress are dependent on glyoxalase I and glutathione. *Biochemical and Biophysical Research Communications*, **337**: 61–67. https://doi.org/10.1016/j.bbrc.2005.08.263

Zampieri M, Ceglar A, Dentener F and Toreti A (2017) Relationship between grain yield and related agronomic traits in bread wheat recombinant inbred lines under water deficit condition. *Environ. Res. Lett*, **12**: 64008. http://dx.doi.org/10.1088/1748-9326/aa723b

Zandalinas SI, Sales C, Beltrán J, Gómez-Cadenas A and Arbona V (2017) Activation of secondary metabolism in citrus plants is associated to sensitivity to combined drought and high temperatures. *Frontiers in Plant Science*, **7**: 1–17. https://doi.org/10.3389/fpls.2016.01954

Zlatev Z and Cebola F (2012) An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emirates Journal of Food and Agriculture*, **24**: 57–72.