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REVIEW PAPER

Influence of Weather Variability on the Growth and Development of Wheat Crop: A Review

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ABSTRACT

Wheat (*Triticum aestivum* L.), the second-most important cereal crop in India, provides food and nutrition security to the majority of the country's people. In the context of a changing climate, it is critical to understand how various weather fluctuations impact wheat crop yields. If wheat is sown at the proper time, it may be more resilient to changes in the weather during its critical stages. Selecting the optimal sowing time to avoid stressful times is crucial to aligning the crop's phenology with the duration of favorable environmental circumstances and achieving maximum yields in a changing climate. Warm temperatures at maturity and low temperatures during vegetative growth are ideal for wheat because it is a cool-season crop.

HIGHLIGHTS

- Temperature and radiation are the prime environmental factors affecting the growth and development of wheat by influencing the crop phenology and yield.
- The variations in average growing-season temperatures of ±2 °C can cause decline in grain yield by 50% which can be attributed to enhanced leaf senescence due to eleveated temperatures.

Keywords: Cereal crop, critical stages, climate, vegetative growth, temperatures, *Triticum aestivum*

The majority population of India depends heavily on wheat (*Triticum aestivum* L.), which is the country's second-most important cereal crop. This article's goal is to understand the relationship between crop and weather in wheat crop. Understanding the impact of various weather variations on wheat crop productivity is important in light of the changing climatic scenario. Wheat is a thermosensitive and photo periodically long day crop. It may grow in a range of conditions with significant seasonal variations in temperature and precipitation during the growing season. The primary crop of the winter is wheat, which has specific needs for light and temperature in order to germinate, grow, and bloom (Dabre *et al.* 1993). Wheat may be affected by a variety of environmental conditions, including extremely cold temperatures and heavy rain during one season and mild temperatures and little rain during another. It is possible for these serious situations to arise at several points during a single growing season. To handle wheat under these conditions and get the highest yield is a very difficult undertaking. Major agrometeorological factors that affect all aspects and phases of growth are temperature, humidity, and radiation. Temperature is a very important component of climate, which determine the seedling time and consequently the rate and duration of growth and productivity of

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the crop (Pal *et al*. 2001). The majority of physical and chemical processes in plants are regulated by temperature, and these activities in turn affect the rate at which a plant grows and develops into maturity. Agroclimatic indicators, such as heat units, photothermal units, and heliothermal units, are helpful in crop planning because they evaluate agroclimatic resources and show how agrometeorological variables affect crop growth at various phases. (Bauer *et al*. 1985). According to the crop's phenological stage and variety, crop reactions to variations in temperature fluctuate (Shpiler and Blum, 1986). Phenology is a plant growth progress largely driven by meteorological conditions (Batts *et al*. 1996; Menzel.2000; Menzel *et al*. 2006; Estrella *et al*. 2007; Ma *et al*. 2011). Phenological shifts are essential markers of alterations in the climate and other environmental factors. (Zheng *et al*. 2002; Diskin *et al*. 2012). Since wheat is a crop of the cold season, it grows best in cold temperature during vegetative development and warm weather during maturity. To increase crop productivity, one needs to understand weather variable thresholds and the way they relate to crop phenology and yield. (Sattar *et al.* 2017). Temperature is one of the main climate factor that affects crop yield by determining the sowing time followed by, in consequently, the duration of various phenophases. (Tewari and Singh, 1993). Every genotype requires definite days to attain certain physiological stage of growth. Many workers have identified cardinal temperatures for various physiological processes and growth stages of wheat (Porter and Gawith, 1999) and for optimum yield during some phenophases (Faroooq *et al.* 2011, Vijaya Kumar *et al.* 2013). Porter and Gawith, (1998) showed that the optimum temperature range for the early growth stages of wheat is lower than the threshold for the later growth stages—a temperature range of 12–25°C is congenial for seed emergence, while the delicate temperature for the grain-filling phase is 35.4°C. Crop weather relationships can be used to demonstrate how variations in temperature and solar radiation during the period of the development of a crop affect the crop productivity (Bal *et al.* 2018). In most of the worldwide wheat-growing regions, high temperatures are a significant factor limiting wheat (*Triticum aestivum* L.) yield (Prasad *et al.* 2008). Low photosynthetic rate and shorter grain filling duration at temperatures above 30°C have a detrimental effect on wheat growth and development, including small grains, at 25–35°C (Farooq *et al*. 2011). Damaged vegetative structure negatively affects the reproductive structure and grain yield (Ahmad *et al.*2018). Additionally, under water stress circumstances (low rainfall), warm temperatures (above 30°C) greatly decrease plant photosynthesis (Farooq *et al*. 2011).

Phenological development of wheat crop under weather variabilities

Sowing time of a crop can alter the weather conditions for all the phasic and growth stages of the crop due to weather variabilities caused by different sowing time of the crop. Phenology of wheat crop is significantly influenced by the interaction effect of sowing times and wheat genotypes. One of the key elements influencing grain production and quality is the planting date (Ferrise *et al*. 2010). The optimum sowing date depends on rainfall and temperature (Jackson *et al*. 2000) to maintain high grain yields. When wheat is sown at the ideal time, it can withstand weather changes during its most vulnerable phases, but in late sown condition, it may experience terminal heat stress during the reproductive phase, when temperature changes will have a greater impact on yield. To maximize yields in a changing climate, it is essential to match the phenology of the crop to the duration of favorable environmental circumstances by choosing the optimum time to sow in order to prevent adverse conditions. By altering the sowing date, a favorable microclimate can be produced (Pal *et al.* 1996) that mitigates the harmful effects of high temperatures throughout the reproductive growth period. In order to maximize grain yields, enhanced variety selection and sowing time selection are essential management decisions. The wheat that is sown late in the growing season experiences stress from low temperatures in early growth stages and high temperatures stress during the later growth phases (Alam *et al*. 2013). (Bannayan *et al*. 2013) yield was shown to increase with early sowing but to decrease with late sowing. Each genotype had a distinct number of days for each phenological stage. All genotypes considerably reduced the number of days needed to reach different phenological stages of growth under late growing conditions (Roy *et al*. 2018). A crop can be planted on different dates each year, exposing it to varying temperature regimes during its growing season. This allows researchers to investigate how crops respond to temperature without having to create fake conditions in controlled facilities (Vijaya Kumar 2015). (Ahmed and Farooq 2013) observed that with the longest time to complete phenological stages, early-sown wheat achieved the highest values for GDD, which seemed to decrease with later delayed sowing. The impact of crop management techniques, such as planting dates and plant genetics, as well as the interaction of these two factors with environmental factors, are illustrated using crop growth models (Hatfield *et al.* 2011; Jones *et al.* 2003; Asseng *et al.* 2015; Ahmed, *et al.* 2018; Ullah *et al.* 2019; Hussain *et al.* 2020; Rahman *et al.* 2019). The various weather conditions have an impact on heat use efficiency (HUE), which is a crucial aspect in crop development. Wheat was found to have a higher heat use efficiency in early-sown crops, and a lower heat use efficiency in later-sown crops (Singh *et al.* 2016). Therefore, early wheat crop sowing appears to be crucial for effectively utilizing heat under changing conditions (Kumari *et al.* 2009). Kaur and Pannu, 2008 reported that the crop's heat unit consumption and thermal use efficiency were greatly decreased by the seeding delay. Environmental conditions have a major impact on wheat grain yield when it is sown late. It is evident that when plants are seeded later than usual, they would be exposed to more unfavorable weather circumstances, such as low temperatures and less thermal exposure from seeding to wintering stage.

Leaf area index of wheat crop under weather variabilities

The leaf area index is the most helpful metric for illustrating the rate that a plant is growing and developing overall under different weather circumstances. Leaf area index is a crucial metric for crop growth research since it measures a crop's capacity for producing dry matter in terms of the quantity of photosynthesis synthesized and the amount of radiation intercepted. The thermal time affects the development and growth of crop. In a semiarid location, high temperatures have a significant impact on wheat leaf area index and apparent photosynthesis (Johnson *et al.* 1981). Vashisth *et al.* (2022), discovered when researching three wheat cultivars that the LAI profile often increased throughout the vegetative phase, peaked during the flowering phases, and subsequently decreased as a result of senescence when sown timely, late, or extremely late. When compared to late and extremely late seeded crops, the timely sown crop displayed the highest LAI. The peak LAI values were 3.82, 4.32, 4.51 under timely sown crop, 2.32, 2.55, 2.74 under late sown crop and 2.21, 2.45, 2.58 under very late sown wheat variety viz., PBW-723, HD-2967 and HD-3086, respectively. The date at which the maximum LAI was reached varied depending on the planting circumstances. For timely and late-planted crops, it was 90 DAS, and for very late-planted crops, it was 80 DAS. These values show that the terminal heat stress accelerated the development of leaf area, although at a reduced rate. The reduction of leaf area in terms of percentage was higher in very late sown crop as compared to the timely sown crop was 44 to 58%, 41 to 52% and 34 to 47% in PBW-723, HD-2967 and HD-3086 respectively. Relative to a timely and late-planted harvest, a very late-planted crop reached its peak LAI significantly early and had a lower value. This suggests that a delay in planting led to a notable reduction in crop growth and a shortened growing season. Pal *et al.* (2012) also found that the maximum LAI was obtained from an early November sowing (20 November), as a result of the crop developing and growing more successfully at all stages than from a late December sowing (15 December), and the least LAI was obtained from an extremely late January sowing (9 January). The LAI was significantly reduced by seeding later than planned, while genotypes at all stages had no meaningful impact. Additionally, late seeding decreases the accumulation of nitrogen and dry matter in wheat crops (Ehdaie & Waines 2001). As a result, delaying wheat seeding often has a detrimental effect on tiller development, crop growth in general, and yield (Hussain *et al.* 2017; Kaur 2017). In addition, delayed sowing raises the risk of crops being exposed to high temperatures during the grain filling stage, which is detrimental to the creation of ultimate yield, grain filling, and leaf photosynthesis. These are regarded as the primary stresses for wheat production in a variety of global locations (Garg *et al.* 2013).

Tillers of wheat crop under weather variabilities

Between the time of planting and the point at which the plant has two tillers, the amount of heat units accumulated by the wheat plant affects the rate of growth, leaf count, and number of tillers developed. The relationship between leaf growth and heat units (derived from daily average temperatures). After the plant produces three leaves, it requires 300–400 heat units to start developing tillers. The quantity of leaves, which is a function of heat units accumulated, determines the rate at which tillers are generated. Numerous studies have demonstrated that warm environments with little to no stress from cold periods or nutritional deficiency are essential for early growth to occur quickly (Oakes *et al*. 2016). Tillers with this kind of growth are able to produce enormous spikes with an increasing number of larger kernels. Crops that are sown later than expected are exposed to adverse weather conditions, such as low temperatures, which might affect their capacity to germinate, tiller, and produce a large number of plants (Borràsgelonch *et al*. 2012; Fernanda *et al*. 2013). Sunil Kumar *et al*. (2015) discovered that, in comparison to other sowing dates, crop seeded on November 5th generated noticeably higher plants at tillering, earing, and harvesting. The low temperature that existed at the time of germination may have contributed to the overall drop in plant height under delayed sowing, slowing plant growth and ultimately reducing plant height. Due to greater temperatures during distinct phenophases, late seeding allowed for a shorter growth period, which led to an earlier flowering and maturation of the crop and, ultimately, a shorter height of plant. Tewari and Singh (1995) and Tahir *et al*. (2009) also recorded similar results. Heat shock significantly lowers the rate of photosynthesis in leaves toward the final stage of tillering, and substantially lowers the rate of photosynthesis and grain growth during grain filling (Egli 2004; Schapendonk *et al.* 2007; Yang *et al.* 2008). Heat stress decreases leaf area (Warrington 1977), prolongs the vegetative growth period (Saini 1988), reduces the number of leaves (Acevedo *et al.* 1990), affects shoot mass, grain mass, and sugar content of grains (Blum *et al.* 1994), and has an impact on plant photosynthesis and maturation (Al-Khatib and Paulsen 1984). The rate at which leaves initiate has an impact on crop growth, radiation absorption, and leaf development, all of which are enhanced by high temperatures (Loomis and Connor 1992). According to Kase and Catsky (1984), high temperatures cause wheat to grow more quickly and have more leaf area. Pathanina *et al.* (2018) shown from their research that when the date of planting was moved from November 20 to December 20, ear length fell gradually and dramatically. Comparing the 20th of November to all other sowing dates at par with the 5th of November sowing, a significantly larger ear length (in centimeters) was noted. According to Jat *et al.* (2013), ear length decreased as planting time was delayed. The reduced amount of productive tillers, limited tillering ability, and poor tiller development resulted from late seeding, early growth inhibition, and a shorter vegetative growth phase. While seeding later in the growing season may increase the number of tillers around the jointing stage, this benefit is not sustained. The percentage of productive tillers dropped as a result of a considerable decrease in tillers at the mature stage as compared to normal sowing (Liu *et al.* 2021). The higher seeding rate may compensate for the winter wheat that is sown late and has less tillers (Wang *et al.* 2016; Ma *et al.* 2018). Delaying sowing may result in a significant decrease in dry matter formation and final yield; this could be explained by reducing the vegetative growth time and quantity of tillers (Shah *et al*. 2020).

Flowering and Milking of wheat crop under weather variabilities

Drought and abnormally high or low temperatures during the heading and flowering stages are harmful to wheat. The wheat stage that is most susceptible to temperature stress is the flowering to milking stage. Farmers must complete sowing wheat by late November in order to avoid terminal heat stress and achieve a greater yield (Sattar *et al.* 2020). Crop sown early by 15 November would finish its most sensitive flowering period within 15-20 February, beyond which increase in day temperature above 25°C accompanied by dry westerly winds likely to interfere with pollination of wheat crop, consequently adversely influencing the grain setting (Anon 2009). The critical thresholds of maximum and minimum temperatures during different phenological stages of wheat required for realization of different yield levels. Both maximum and minimum temperatures play significant role in influencing wheat yield. Grain yield was decreased by maximum temperatures exceeding 30.2 and 33.1°C during 50% of the flowering to milk and 50% of the flowering to maturity stages, respectively. In a similar way, grain production is negatively impacted by minimum temperatures of 16.8 and 18.0 degrees Celsius during 50% of flowering to milking and 50% of flowering to maturity, respectively. When dry westerly winds are prevalent in the wheat crop from flowering to maturity, the maximum temperature tends to rise throughout these periods, which prevents the wheat grains from setting (Sattar *et al.* 2020). In wheat, the milking stage is determined to be the most important stage. The grain yield will ultimately be influenced by weather factors. At this point in time, it has been discovered that rainfall has a favorable impact on grain yield while the maximum temperature, minimum temperature, and sunshine have a negative correlation (Thakur *et al.* 2018). Late seeding accelerates reproductive growth and decreases grain-filling because it postpones flowering and exposes crops to high temperatures during the grain-filling stage (Bailey-Serres *et al.* 2019; Dubey *et al.* 2019).

Rezaei *et al.* (2018) discovered that, in comparison to winter wheat cultivars cultivated in the 1950s and 1960s, the temperature sum required from emergence to flowering for present cultivars of the crop has decreased by 14–18%. Variations in the mean temperature and cultivar characteristics contributed similarly to the trends in the flowering day, whereas the impacts of variations in the sowing day were minimal, according to the trends in the flowering day that were derived from a phenology model parameterized with the field observations. Changes in the timing of plant activity, or phenology, provide some of the best indicators that species and ecosystems are being impacted by environmental change, even though plants are highly adapted to their seasonal environment. Delaying sowing can also result in early flowering, which can shorten the time it takes for different stages of crop growth (Liu *et al.* 2021) demonstrated that, in comparison to a normal sowing, the growth period of the crop from sowing to flowering was delayed by 7.5 days under the conditions of the extremely late seeding. A possible explanation for the poor performance under delayed sowing could be the shortening of the important phenological phase, which is an important factor in influencing the photoperiod and productivity of crops (Ferrise *et al.* 2010; Sattar *et al.* 2010).

Anthesis of wheat crop under weather variabilities

Crop reaction to temperature events can be measured by the timing of phenological events in the crop, such as anthesis, maturity, etc. (Van Bussel *et al.* 2011; White *et al.* 2011). When wheat is exposed to temperatures above 31°C for five days before to anthesis, a greater proportion of sterile grains develop (Wheeler *et al.* 1996). Winter wheat anthesis timing is primarily determined by the interplay of genetic factors and environmental factors (temperature and photoperiod), which are further influenced by crop management techniques including cultivar selection and sowing date (Kirby *et al.* 1987). Amrawat *et al.* (2013) the crop sown on November 5th (either early or on time) produced the best yields of grain (64.86 q ha^{-1}) and straw (108.84 q ha^{-1}), which was roughly equivalent to the crop sown on November 20th (mid), but much greater than the yields recorded on late sowing dates. Elevated temperatures force crop to finish their growth stage more quickly, leading to an earlier maturity and shortened life cycle, reduced accumulation of biosynthetic products, and eventually subpar grain formation. Temperature, solar radiation, saturation deficit, and sunshine hours were significant climate variables that also influenced the number of days from sowing to anthesis and from anthesis to maturity in several wheat cultivars. Different weather conditions also having an impact on the pre-anthesis and post-anthesis phases, explaining 28–68% and 60–85% of the variation in these phases, respectively (Kumar, S. and Prasad, R. 2016). However, high temperatures before anthesis can reduce the detrimental effects of heat stress after anthesis on the remobilization of stem reserve carbohydrates and the formation of starch in wheat grains (Wang *et al.* 2012).

However, the duration and timing of distinct phenological stages or phases strongly impact winter wheat yield (Jamieson *et al.* 1998). The duration of the grain-filling stage, a crucial step in yield production, slightly extends even if the warming trend shortens the durations of dormancy to vegetative, vegetative to anthesis, and the entire growth period. Temperature also has a major influence on grain-filling period, which decreases in warmer climates (Sofield *et al*. 1977). But because of early anthesis, the grain-filling phase occurs at a lower temperature than usual. This causes a little delay in anthesis to maturity, along with cultivar changes. Climate change causes changes that favor early maturity and anthesis (Xiao *et al*. 2012). These changes mitigate the impact of high temperature on the grain-filling phase to some extent (Tao and Zhang 2012). For grain yield, the temperature during grain filling and growth is crucial. Grain weight tends to decrease during this phase at temperatures exceeding 25°C.

Dry matter production and Yield under weather variabilities

The strongest indicators of a crop's overall performance and reaction to weather are its dry matter production and accumulation (Mall *et al.* 2000). The distribution and accumulation of dry matter determine crop yield formation (Zheng, Xu & Wu 2013). Moneith (1972) discovered a correlation between sun radiation and wheat grain production. According to his research, the amount of light that is intercepted, the effectiveness with which it is converted to dry matter, and the distribution of dry matter among grains all contribute to grain yield.

Higher temperatures or heat stress conditions during the last stages of wheat growth also have an impact on wheat production. Elevations over the optimal temperature threshold for each phase may result in a decrease in the overall yield of grains. Grain filling is facilitated by hot, dry conditions that lower photosynthetic rate and limit the amount of newly formed assimilates that may be added (Alvaro *et al.* 2008). Independent of day duration and vernalization, heat stress reduces the length of the grain filling phase (Midmore *et al.* 1982). Many researchers have determined how temperature affects wheat crop development later on, especially after heading (Wardlaw *et al.* 1980; Rawson 1986). It has been established by Chowdhury and Wardlaw (1978) and Fischer (1985) that, in semitropical and tropical climates, an average temperature of 15 °C during grain filling is nearly ideal for maximum grain weight. Due to a reduction in grain filling length, high temperatures during the wheat grain filling period significantly limit kernel weight and grain yield (Sayed and Gadallah 1983; Weigand and Ceullar 1981).

AcAccording to studies by Wheeler *et al.* (1996) and Batts *et al.* (1997), high temperatures lower wheat production. Grain weight is decreased by heat stress through a reduction in grain growth rate (Viswanathan and Khanna-Chopra, 2001) and duration of growth (Gebeyehou *et al.* 1982). Wheat crop-weather relationship research showed that the date of sowing has a major impact on the yield of grains. By adjusting the sowing date, the crop can be more effectively adapted to a specific thermal environment, ensuring its productivity over time. The date of sowing has a significant impact on yield; if the date is delayed, the crop may mature earlier due to temperature rise, which would reduce the amount and size of grains (Parihar and Tripathi 1989). Delays in seeding might result in a notable decrease in grain yield. Significant reduction was noted in the case of the late-condition sowing on December 18 (Basu *et al.* 2014). Generally speaking, it is predicted that rising temperatures will shorten the wheat growth cycle and decrease productivity. Increased temperatures cause the crop to get less solar radiation and shorten the growth season, which lowers production (Mearns *et al*. 1997; Van Oijen and Ewert 1999). The temperature of the canopy also has a significant impact on the crop's ultimate grain production. Grain yield and dry matter formation in crops are negatively impacted by canopy temperature (Das *et al.*1993; Chakravarti *et al.* 2010). Research has shown that both crop dry matter accumulation and crop yield are negatively impacted by high canopy temperatures during the reproductive stage (Chakraborty 1994; Onyibe *et al.* 2003; Tyagi *et al.* 2003 and Chakravarti *et al.* 2010).

When compared to timely sown and late sown crops, the final grain yield production at harvest was considerably lower in the extremely late sown crop. The maximum yield reduction occurred in PBW-723, followed by HD-2967 and HD-3086. This could be because the higher temperature reduced vegetative growth. The percent reduction of yield could be 37.7, 9.2, 6.3% in varieties PBW-723, HD-2967, and HD-3086 under very late sown crop compared to the timely sown crop (Roy *et al.* 2018). Liu *et al.* (2021) state that planting winter wheat before or after the ideal period may prevent it from reaching its maximum genetic production potential. They discovered that their investigation assessed variations in grain yield as well as the biological impacts brought on by various sowing dates. They found that for every day that the planting was done earlier or later than the typical sowing date, the grain yield decreased by 0.97 to 0.22%.

Different dates of sowing and varieties had a substantial impact on the growth of wheat varieties, as evidenced by the study conducted by Singh *et al.* (2022) on growth features such as plant height, number of tillers, fresh weight, and dry weight of plant. In comparison to late planting (30th December), early or timely (30th November) sowing was superior in terms of growing plant height (8.51%), tiller (14.90%), and dry matter accumulation (13.38%). Compared to late planting, which has short growth and a short time period, early or timely sowing on November 30th may have allowed plants more time for growth and development, as seen by the maximum growth rate of the plants.

Thakur *et al.* (2018) investigated the correlations between average wheat yield for 14 crop seasons (2001–02 to 2015–16) for the Kanchan variety, as well as the impact of climatic factors such as maximum temperature, minimum temperature, and sunshine variation on the yield of different stages of wheat during Rabi season. Their research found that, rather than factors related to producing crops for various phenological stages, the year-to-year variation in grain production may be more pronounced due to variation in meteorological variables and their inter-relationship impacts. Increased sunshine levels during the 50% flowering and milking stages can negatively impact normal functioning and cause physiological stress, which in turn can negatively impact grain yield. On the other hand, higher sunshine levels during the CRI, dough, and physiological maturity stages have been found to contribute to higher grain yield production. The maximum temperature throughout the crop's reproductive period was shown to be significantly connected with grain yield; however, no significant connections were seen with other factors.

CONCLUSION

After taking into account all of the reviews that have been mentioned thus far, it is clear that weather variability has a significant impact on the phenological development of the wheat crop. Sowing time is a crucial aspect that determines weather variability during crop growth and impacts the growth and development of wheat crops at different stages, among other climatic parameters. Crop growth and yield are determined by the combined influence of meteorological events that occur at various phases of growth.

REFERENCES

A.D. 1988. Impact of temperature, photoperiod and light intensity on flowering, grain number and yield in wheat. *In:* proceedings of the International Congress of Plant Physiology. New Delhi, India. Feb15-20 (Eds) Sinha, S.K., Sane, P.V. Bhargava, S.C and P.K. Agrawal. **1**: 101- 113.

Acevedo, E., Nachit, M. and Ortiz, G. 1990. Effects of heat stress on wheat and possible selection tools for use in breeding for tolerance. In: wheat for the non-traditional warm areas. A proceeding of International conference. July 29-August 3. Maxixo (ed.) Saundess, D.A. Pp: 401-420.

Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S.A., Khaliq, T., Rasul, F., Saeed, U., Rahman, M.H.U., Hussain, J. and Baig, I.A. Impact of Climate Change on the Rice–Wheat Cropping System of Pakistan. In *Handbook of Climate Change and Agroecosystems*; The Agricultural Model Inter-comparison and Improvement Project Integrated Crop and Economic Assessments, Imperial College Press: London, UK; pp. 219–258.

Ahmed, M. and Farooq, S. 2013. Growth and Physiological Responses of Wheat Cultivars under Various Planting Windows. *The J. Anim. & Plant Sci.*, **23**(5): 1407-1414.

Ahmed, I., Rahman, M.H.U., Ahmed, S., Hussain, J., Ullah, A. and Judge, J. 2018. Assessing the impact of climate variability on maize using simulation modeling under semi-arid environment of Punjab, Pakistan. *Environ. Sci. Pollut. Res.*, **25**: 28413–28430.

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

Al-Khatib, K. and Paulsen, G.M. 1984. Mode of high temperature injury to wheat during grain development. *Plant Physiol.*, **61**: 363–368.

Alvaro, F., Isidro, J., Villegas, D., Garcia del Moral, L.F. and Royo, C. 2008. Breeding effects on grain filling, biomass partitioning and remobilization in Mediterranean durum wheat. *Agron. J.*, **100**: 361–370.

Amrawat, T., Solanki, N.S., Sharma, S.K., Jajoria, D.K. and Dotaniya, M.L. 2013. Phenology growth and yield of wheat in relation to agrometeorological indices under different sowing dates. *Af. J. of Agril. Res.*, **8**(49): 6366-6374.

Anon. 2009. Annual Progress Report, All India Coordinated Research Project on Agrometeorology (Indian Council of Agricultural Research), RAU, Pusa, Bihar, pp. 52.

Aslam, M.A., Ahmed, M., Stöckle, C.O., Higgins, S.S. and Hayat, R. 2017. Can growing degree days and photoperiod predict spring wheat phenology. *Front. Environ. Sci.*, **5**: 57–68.

Asseng, S., Ewert, F., Martre, P., Rotter, R.P., Lobell, D.B., Cammarano, D., Kimball, B.A., Ottman, M.J., Wall, G.W. and White, J.W. *et al*. 2015. Rising temperatures reduce global wheat production. *Nat. Clim. Chang.*, **5**: 143–147.

Bailey-Serres, J., Parker, J.E., Ainsworth, E.A., Oldroyd, G.E.D. and Schroeder, J.I. 2019. Genetic strategies for improving crop yields. *Nature*, **575**(7781): 109-118.

Bal, S.K., Bhagat, K.P., Chowdhury, A.R., More, N., Suman, S. and Singh, H. 2018. Managing Photo-thermal Environment for Improving Crop Productivity. *In:* "Advances in Crop Environment Interaction". pp. 153-179, Springer Nature Singapore Pte Ltd.

Bannayan, M., Crout, N.M.J. and Hoogenboom, G. 2003. Application of the CERES Wheat model for within-season prediction of winter wheat yield in the United Kingdom. *Agron. J.*, **95**(1): 114-125.

Basu, S., Parya, M. Dutta1, S.K., Maji, S., Jena, S., Nath, R. and Chakraborty, P.K. 2014. Effect of canopy temperature and stress degree day index on dry matter accumulation and grain yield of wheat (*Triticum aestivam* L.) Sown at different dates in the indo-gangetic plains of eastern India. *Indian J. Agric. Res.*, **48**(3): 167-176.

Batts, G.R., Morison, J.I.L., Ellis, R.H., Hadley, P. and Wheeler, T.R. 1997. Effect of CO_2 and temperature on growth and yield of crops of winter wheat over four seasons. *European J. Agron*., **7**: 43-52.

Batts, G.R., Wheeler, T.R. and Morison, J.L. 1996. Developmental and tillering responses of winter wheat (*Triticum aestivum*) crops to CO_2 and temperature. *J. Agr. Sci.*, **127**: 23–35.

Bauer, A., Frank, A.B. and Black, A.L. 1985. Estimation of spring wheat grain dry matter assimilation from air temperature. *Agron. J.*, **77**: 743-752.

Blum, A., Sinmena, B., Mayer, J., Golan, G. and Shpiler, L. 1994. Stem reserve mobilization supports wheat-grain filling under heat stress. *Aust. J. Plant Physiol.*, **21**: 771–781.

Borràsgelonch, G., Rebetzke, G.J., Richards, R.A., Romagosa, I. and Ha, C. 2012. Genetic control of duration of pre-anthesis phases in wheat (*Triticum aestivum* L.) and relationships with leaf apperance, tillering and dry matter accumulation. *J. of Experimental Bot.*, **63**(1): 69-89.

Chakraborty, P.K. 1994. Effect of date of sowing and irrigation on the diurnal variation in physiological processes in the leaf of Indian mustard (*Brassica juncea*). *J. Oilseeds Res.*, **11**(2): 210-16.

Chakravarti, A.K., Moitra, R., Mukherjee, A., Dey, P. and Chakraborty, P.K. 2010. Effect of planting methods and mulching on the thermal environment and biological productivity of groundnut. *J. Agromet.*, **12**(1): 77-80.

Chowdhury, S.I. and Wardlaw, I.F. 1978. *Aus. J. Agri. Res.*, **295**: 205-223.

Dabre, W.M., S.B. Lall and Lngole, G.L. 1993. Effects of sowing dates on yield, ear number, stomatal frequency and stomatal index in wheat. *J. Maharashatra Agric. Univ.*, **18**: 64-66.

Das, D.K., Mishra, K.K. and Kalra, N. 1993. Assessing growth and yield of wheat using remotely sensed canopy temperature and spectral indices. *Int. J. Remote Sens.*, **14**(17): 3081-92.

Diskin. E., Proctor, H., Jebb, M., Sparks, T. and Donnelly, A. 2012. The phenology of *Rubus fruticosus* in Ireland: herbarium specimens provide evidence for the response of phenophases to temperature, with implications for climate warming. *Int. J. Biometeorol*.

Dubey, R., Pathak, H., Singh, S., Chakrabarti, B. and Fagodiya, R.K. 2019. Impact of sowing dates on terminal heat tolerance of different wheat (*Triticum aestivum* L.) cultivars. *National Academy Science Letters*, **42**: 445-449.

Egli, D.B. 2004. Seed- fill duration and yield of grain crops. *Adv. Agron.*, **83**: 243-79.

Ehdaie, B. and Waines, J.G. 2001. Sowing date and nitrogen rate effects on dry matter and nitrogen partitioning in bread and durum wheat. *Field Crops Res.*, **73**: 47-61.

Estrella, N., Sparks, T.M. and Menzel, A. 2007. Trends and temperature response in the phenology of crops in Germany. *Glob. Chang Biol.*, **13**: 1737–1747.

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

Vijaya Kumar, P., Rao, V.U.M., Bhavani, O., Dubey, A.P., Sidhu, P.K., Patel, S.R. and Venkateswarlu, B. 2013. Optimizing sowing dates and selection of varieties of wheat through long-term crop and weather analysis, *J. Agrometeorology.*, 15: 67-72.

Farooq, M., Bramley, H., Palta, J. and Siddique, K. 2011. Heat Stress in Wheat during Reproductive and Grain-Filling Phases. *Crit. Rev. Plant Sci.*, **30**: 491–507.

Fernanda, D.M., Chapman, S.C., Rattey, A.R., Jodi, N., Song, Y.H., Christopher, J.T. and Matthew, R. 2013. Developmental and growth controls of tillering and water-soluble carbohydrate accumulation in contrasting wheat (*Triticum aestivum* L.) genotypes: can we dissect them? *J. of Experimental Bot.*, **64**(1): 143-160.

Ferrise, R., Triossi, A., Stratonovitch, P., Bindi, M. and Martre, P. 2010. Sowing date and nitrogen fertilisation effects on dry matter and nitrogen dynamics for durum wheat: an experimental and simulation study. *Field Crops Res.*, **117**: 245-257.

Fischer, R.A. 1985. *In:* Proc. Inter. Symp. on Physiological Limitations to Producing Wheat in Subtropical and Tropical Environments and Possible Selection Criteria held at CYMMYT, Maxico, pp. 290-330.

Garg, D., Sareen, S., Dalal, S., Tiwari, R. and Singh, R. 2013. Grain filling duration and temperature pattern influence on the performance of wheat genotypes under late planting. *Cereal Res. Communications*, **41**(3): 500-507.

Gebeyehou, G., Knott, D.R. and Baker, R.J. 1982. Rate and duration of grain filling in durum wheat cultivars. *Crop Sci.*, **22**: 337–340.

Hatfield, J.L.,; Boote, K.J., Kimball, B.A., Ziska, L.H., Izaurralde, R.C., Ort, D., Thomson, A.M. and Wolfe, D. 2011. Climate Impacts on Agriculture: Implications for Crop Production. *Agron. J.*, **103**: 351–370.

Heiniger, R. Tilley, M., Oakes, J., Post, A. and Wilkerson, G. Adaptive Wheat Management: Increasing Wheat Yield by Adjusting for Weather Conditions. Published by: NC State Extension.

Hussain, S., Khaliq, A., Bajwa, A.A., Matloob, A., Areeb, A., Ashraf, U., Hafeez, A. and Imran, M. 2017. Crop growth and yield losses in wheat due to little seed canary grass infestation differ with weed densities and changes in environment. *Planta Daninha*, **35**: 1-15.

Hussain, J., Khaliq, T., Asseng, S., Saeed, U., Ahmad, A., Ahmad, B., Fahad, M., Awais, M., Ullah, A. and Hoogenboom, G. 2020. Climate change impacts and adaptations for wheat employing multiple climate and crop modelsin Pakistan. *Clim. Chang.*, **163**: 253–266.

Jackson, L.F., Dubcovsky, J., Gallagher, L.W., Wenning, R.L. and Wright, S. 2000. Regional barley and common and durum wheat performance tests in California. *Agronomy Progress Report*, **272**: 1-56.

Jamieson, P.D., Brooking, I.R. and Semenov, M.A. 1998. Making sense of wheat development: a critique of methodology. *Field Crop Res*., **55**: 117–127.

Jat, L.K., Singh, S.K., Latare, A.M., Singh, R.S. and Patel, C.B. 2013. Effect of dates of sowing and fertilizer on growth and yield of wheat (*Triticum aestivum*) in an Inceptisol of Varanasi. *Indian J. of Agron.*, **58**: 611-14.

Johnson, R.C., Witters, R.E. and Chia, A.J. 1981. Daily patterns of apparent photosynthesis and evapo-transpiration in a developing winter wheat crop. *Agron. J.*, **73**: 414-418.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T. 2003. The DSSAT cropping system model. *Eur. J. Agron.*, **18**: 235–265.

Kase, M. and Catsky, J. 1984. Maintenance and growth components of dark respiration rate in leaves of C3 and C4 plants as affected by leaf temperature. *Biol. Plant*, **26**: 461–470.

Kaur, C. 2017. Performance of wheat varieties under late and very late sowing conditions. *Int. J. of Curr. Microb. and Appl. Sci.*, **6**(9): 3488-3492.

Kaur, A. and Pannu, R.K. 2008. Effect of sowing time and nitrogen schedules on phenology, yield and thermal-use efficiency of wheat (*Triticum aestivum* L.). *Indian J. Agric. Sci.*, **78**: 366-69.

Kirby, E.J.M., Porter, J.R. and Day, W. 1987. An analysis of primordium initiation in Avalon winter wheat crops with different sowing dates and at nine sites in England and Scotland. *J. Agr. Sci.*, **109**: 123–134.

Kumar, S. and Prasad, R. 2016. Effect of Weather Parameters on Growth, Development and Yield of Wheat (*Triticum aestivum* L.) Varieties Under Mid Hill Conditions of Himachal Pradesh. *J. Bio-Sci.*, **30**(1): 251-258.

Kumar, S., Prasad, R., Rana, M., Jaryal, N., Sehgal S. and Singh, A. 2016. Impact of meteorological variables on wheat (*Triticum aestivum* L.) yield in mid hill conditions of Himachal Pradesh *Eco. Env. & Cons. 22 (April Suppl.): pp. (S183-S188).*

Kumari, P., Wadood, A., Singh, R.S. and Kumar, R. 2009. Response of wheat crop to different hydrothermal regimes under the agroclimatic conditions of Jharkhand. *J. Agromet.*, **11**: 85-88.

Liu, K., Zhang, C., Guan, B., Yang, R., Liu, K., Wang, Z., Li, X., Xue, K., Yin, L. and Wang, X. 2021. The effect of different sowing dates on dry matter and nitrogen dynamics for winter wheat: an experimental simulation study. *Peer J.*, **9**: e11700.

Loomis, R.S. and Connor, D.J. 1992. Crop Ecology. In Productivity and Management in Agricultural System Cambridge University Opress: Cambridege, pp. 492.

Ma, S.C., Wang, T.C., Guan, X.K. and Zhang, X. 2018. Effect of sowing time and seeding rate on yield components and water use efficiency of winter wheat by regulating the growth redundancy and physiological traits of root and shoot. *Field Crops Res.*, **221**: 166-174.

Ma, S.X., Churkina, G. and Trusilova, K. 2011. Investigating the impact of climate change on crop phenological events in Europe with a phenology model. *Int. J. Biometeorol.* DOI: 10.1007/s0048401104786

Mall, R.K., Gupta, B.R.D., Singh, K.K. and Singh, T.K. 2000. Phenology and yield of wheat (*Triticum aestivum* L.) in retlation to growing degree days and photo thermal units. *Indian J. of Agril. Sci.*, **70**: 647-652.

Mearns, L.O. Rosenzweig, C. and Goldberg, R. 1997. Mean and variance change in climate scenarios: methods, agricultural applications, and measures of uncertainty *Climatic Change*, **35**(4): 367-396.

Menzel, A. 2000. Trends in phenological phases in Europe between 1951 and 1996. *Int. J. Biometeorol.*, **44**: 76–81.

Menzel, A., Sparks, T.H. and Estrella, N. *et al*. 2006. European phenological response to climate change matches the warming pattern. *Glob. Chang. Biol.*, **12**: 1969–1976.

Midmore, D.J., Cartwright, P.M. and Fischer, R.A. 1982. Wheat in tropical environments I. Phasic development and spike size. *Field Crops Res.*, **5**: 185–200.

Moneith, J.L. 1972. *J. Agric. Ecol.*, **9**: 747-66.

Oakes, J., Heiniger, R., Crozier, C., Murphy, J. and Wilkerson, G. 2016. "Phyllochron Interval and Yield Response to Planting Date and Fertility in Wheat." *Crop, Forage & Turfgrass Management*, **2**.

Oijen, M.V. and Ewert, F. 1999. The effects of climatic variation in Europe on the yield response of spring wheat cv. Minaret to elevated CO_2 and O_3: an analysis of open-top chamber experiments by means of two crop growth simulation models. *Eur. J. Agron.*, **10**(3): 249-264.

Onyibe, J.E., Ahmed, M.K., Falaki, A.M. and Ramalan, A.A. 2003. Canopy air temperature differential of wheat varieties grown under different soil moisture regime on semi-arid Sudan Savanna. *Disc. & Innov.*, **15**(3/4): 177-85.

Pal, S.K., Verma, U.N., Singh, M.K., Upsani, R.R. and Thakur, R. 2001. Growth and yield of late sown wheat under different irrigation schedules. *Indian J. of Agril. Sci.*, **71**: 664-667.

Pal, S.K., Kaur, J., Thakur, R., Verma, U.N. and Singh, M.K. 1996. Effect of irrigation, seeding date and fertilizer on growth and yield of wheat (*Triticum aestivum* L.). *Indian J. Agron.*, **41**: 386-89.

Parihar, S.S. and Tripathi, R.S. 1989. Response of wheat to nitrogen, irrigation and sowing dates. *Indian J. Agric. Sci.*, **34**: 192-96.

Pathanian, R., Prasad, R., Rana, R.S., Mishra, S. and Sharma, S. 2018. Growth and yield of wheat as influenced by dates of sowing and varieties in north western Himalayas. *J. Pharmacognosy and Phytochem.*, **7**(6): 517-520

Porter, J.R. and Gawith, M. 1999. Temperatures and the growth and development of wheat: a review. *Eur. J. Agron.*, **10**: 23–36.

Porter, J.R. and Gawith, M.1998. Temperatures and the growth and development of wheat: A review. *Eur. J. Agron.*, **10**: 23–26.

Rahman, M.H.U., Ahmad, A., Wajid, A., Hussain, M., Rasul, F., Ishaque, W., Islam, A., Shelia, V., Awais, M. and Ullah, A. *et al*. 2019. Application of CSM-CROPGRO-Cotton model for cultivars and optimum planting dates: Evaluation in changing semi-arid climate. *Field Crop. Res.*, 238: 139–152.

Rawson, H.M. 1986. *Field Crops Res.*, **14**: 197-212.

Rezaei, E.E., Siebert, S., Hüging, H. and Ewert, F. 2018. Climate change effect on wheat phenology depends on cultivar change. *Scientific Reports*, **8**:4891.

Roy, D., Ashisth, A, Krishnan, P., Mukherjee, J. and Goyel, A. 2018. Effect of Weather Parameter on Growth and Yield of Wheat (*Triticum aestivum* L.) Crop under Semi-Arid Environment. *J. of Agril. Physics*, **18**(1): 99-106.

Sattar, A., Cheema, M.A., Farooq, M., Wahid, M.A., Wahid, A. and Babar, B.H. 2010. Evaluating the performance of wheat cultivars under late sown conditions. *Int. J. of Agric. and Biol.*, **12**(4): 1560-853012.

Sattar, A., Kumar, M., Vijaya Kumar, P. and Khan, S.A. 2017. Crop weather relationship in *kharif* rice under Northwest Alluvial Plain Zone of Bihar. *J. Agrometeorol.*, **19**(1): 71-74.

Sattar, A., Singh, G., Singh, S.V., Kumar, M., Kumar, V.P. and. Bal, S.K. 2020. Evaluating Temperature Thresholds and Optimizing Sowing Dates of Wheat in Bihar. *J. of Agrometeorology*, **22**(2): 158-164.

Sattar, A., Singh, G., Singh, V.S., Kumar, M., Vijaya Kumar P. and Bal, S.K. Evaluating temperature thresholds and optimizing sowing dates of wheat in Bihar. *J. of Agrometeorology*, **22**(2): 158-164.

Sayed, H.I. and Gadallah, A.M. 1983. *Field Crop Res.*, **7**: 61-71.

Schapendonk, A.H.C.M., Xu, H.Y., Van Der Putten, P.E.L. and Spiertz, J.H.J. 2007. Heatshock effects on photosynthesis and sinksource dynamics in wheat (*Triticum aestivum* L.). NJAS - Wageningen *J. Life Sci.*, **55**: 37-54.

Shah, F., Coulter, J.A., Ye, C. and Wu, W. 2020. Yield penalty due to delayed sowing of winter wheat and the mitigatory role of increased seeding rate. *Eu. J. Agron.*, **119**: 126120.

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

Shpiler, L. and Blum, A. 1986. Differential reaction of wheat cultivars to hot environments. *Euphytica.*, **35**: 483– 492.

Singh, G., Pandey, S.N., Prajapati, S.K. and Yadav, S. 2022. Effect of Weather Parameters, Date of Sowing on Performance of Wheat Varieties (*Triticum aestivum* L.). *Int. J. of Sci. and Res. (IJSR)*, **7**: 942.

Singh, S., Kingra, P.K. and Singh, S.P. 2016. Heat unit requirement and its utilisation efficiency in wheat under different hydrothermal environments *Ann. Agric. Res. New Series*, **37**(2): 130-140.

Sofield, I., Evans, L.T., Cook, M.G. and Wardlaw, I.F. 1977. Factors influencing the rate and duration of grain filling in wheat. *Aust. J. Plant Physiol.*, **4**: 785–797.

Tahir, M., Ali. A., Nadeem, M.A., 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. *Pak. J. of Life and Soc. Sci.*, **7**(1): 66-69.

Tao, F.L. and Zhang, Z. 2012. Climate change, wheat productivity and water use in the North China Plain: A new super-ensemble-based probabilistic projection. *Agric. For Meteorology*. DOI: 10.1016/j. agrformet.2011.10.003

Tewari, S.K. and Singh, M. 1993. Yielding ability of wheat at different dates of sowing: a temperature development performance. *Ind. J. Agron.*, **38**: 204-209.

Tewari, S.K. and Singh, M. 1995. Influence of sowing date on phase duration and accumulation of dry matter in spikes of wheat (*Triticum aestivum*). *Indian J. of Agron.*, **40**(1): 43-46.

Thakur, A.K., Chaodhary, J.L. Kurre, D. and Durgam, U. 2018. Relationship between the Weather Variables and Wheat Yield under Raipur Condition. *Int. J. Curr. Microbiol. App. Sci.*, **7**(11): 1913-1917.

Tyagi, P.K., Singh, D.P. and Pannu, R.K. 2003. Plant water relations, canopy temperature, photosynthesis and grain yield in wheat genotypes as affected by post anthesis chemical desiccation. *Indian. J. Plant Physiol.*, **8**(4): 329-34.

Ullah, A., Ahmad, A., Khaliq, T., Saeed, U., Rahman, M.H.U., Hussain, J., Ullah, S. and Hoogenboom, G. 2019. Assessing climate change impacts on pearl millet under arid and semi-arid environments using CSM-CERES-Millet model. *Environ. Sci. Pollut. Res.*, **26**: 6745–6757.

Van Bussel, L.G.J., Ewert, F. and Leffelaar, P.A. 2011. Effects of data aggregation on simulations of crop phenology. *Agric. Ecosyst. Environ.*, **142**: 75–84.

Vijaya Kumar, P., Rao, V.U.M., Bhavani, O., Dubey, A.P., Singh, C.B. and Venkateswarlu, B. 2015. Sensitive growth stages and temperature thresholds in wheat (*Triticum aestivum* L.) for index-based crop insurance in the Indo-Gangetic Plains of India. *J. Agric. Sci.*, pp. 1-13.

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

Wang, B., Zhang, Y.H., Hao, B.Z., Xu, X.X., Zhao, Z.G., Wang, Z.M. and Xue, Q.W. 2016. Grain yield and water use efficiency in extremely-late sown winter wheat cultivars under two irrigation regimes in the North China Plain. *Plos One*, **11**(4): e0153695.

Wang, X., Cai, J., Liu, F., Jin, M., Yu, H., Jiang, D. and Cao, W. 2012. Pre-anthesis high temperature acclimation alleviates the negative effects of post-anthesis heat stress on stem stored carbohydrates remobilization and grain starch accumulation in wheat. *J. of Cereal Sci.*, **55**(3): 331-336.

Wardlaw, I.F. *et al.* 1980. *Aust. J. Plant Physiol.*, **7**: 387-400.

Warrington, I.J., Dunstone, R.L. and Green, L.M. 1977. Temperature effects at three developmental stages on yield of the wheat ear. *Aust. J. Agric. Res.*, **28**: 11-27.

Wheeler, T.R., Hong, T.D., Ellis, R.H., Batts, G.R., Morison, J.I.L. and Hadley, P. 1996. The duration and rate of grain growth, and harvest index, of wheat (*Triticum aestivum L.*) in response to temperature and CO_2. *J. of Experimental Bot.*, **47**(5): 623-630.

Wheeler, T.R. Hong, T.D. Ellis, R.H. Batts, G.R. Morison, J.I.L. and Hadley, P.1996. The duration and rate of grain growth, and harvest index, of wheat (*Triticum aestivum* L.) in the impact of extreme heat and frost events on wheat crop production: are-view response to temperature and CO_2. *J. Exp. Bot.*, **47**: 623–630.

White, J.W., Kimball, B.A. and Wall, G.W. 2011. Responses of time of anthesis and maturity to sowing dates and infrared warming in spring wheat. *Field Crop Res.*, **124**: 213–222.

Wiegand, C.L. and Ceullar, J.A. 1981. *Crop Sci.*, **215**: 95-101.

Xiao, D. Tao, F. Liu, Y., Shi. W. Wang, M. Liu, F. Zhang, S. and Zhu, Z. Observed changes in winter wheat phenology in the North China Plain for 1981–2009. *Int. J. Biometeorol.* DOI: 10.1007/s00484-012-0552-8.

Yang, W., Peng, S., Dionisio-Sese Rebecca, M.L., Laza, C. and Visperas, R.M. 2008. Grain filling duration, a crucial determinant of genotypic variation of grain yield in field grown tropical irrigated rice. *Field Crops Res.*, **105**: 221-27.

Zheng, J.Y., Ge, Q.S. and Hao, Z.X. 2002. Impacts of climate warming on plants phenophases in China for the last 40 years. *Chin. Sci. Bull.*, **47**: 1826–1831.

Zheng, Y.F., Xu, J.X. and Wu, R.J. 2013. Effects of different shading condition on dry matter accumulation and distribution of winter wheat. *Chinese J. of Agrometeorology*, **34**(1): 64-73.