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# Sensitivity analysis of four wheat cultivars to varying photoperiod and temperature at different phenological stages using WOFOST model

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## ABSTRACT

The sensitivity analysis of three *T. aesivum* (GW 322, GW 496 and GW 366) and one *T. durum* (GW 1139) cultivar of wheat was performed to see the possible change in the grain yield of wheat due to changed sunshine hours (BSS), maximum and minimum temperatures using WOFOST model. The potential condition was assumed with congenial weather and adequate management practices. The results showed that the increase in sunshine hours was found to increase the yield in all cultivars and *vice versa.* The rise in maximum and minimum temperatures had adverse effect on wheat yield. The increase in the maximum temperature by 5°C may cause reduction in yield by 24 to 29%. The effect of the minimum temperature was also of the similar order, but the varietal differences were observed. Among the cultivars, GW 496 was found to be most sensitive to maximum temperature and less to bright sunshine hours. Among the different stages, flowering to dough stage was found to be most sensitive stage.

**Key words*:*** Wheat, sensitivity, photoperiod, temperature, WOFOST etc.

Wheat is a cool-season crop. Cool weather during vegetative development and warm weather for maturity are reckoned ideal for wheat. Understanding the reaction of local wheat cultivars to varying environmental conditions can improve regionally wheat yield and grain quality. When plants are exposed to longer day lengths, production is often improved through a balance between photosynthesis and respiration (Mitchell *et al.*, 1991). Warm temperatures during the early growth of wheat are likely to retard the heading stage (Warren and John, 1963). Exclusively high or low temperatures and moisture stress during the heading and flowering stages are harmful to wheat. Temperatures above 25°C during the development and grain filling periods tend to depress the grain weight. The temperature influences the growth and yield of wheat mainly during the vegetative and reproductive stages (Marcellos and Singie, 1972; Rawson, 1993). Temperature strongly affects the plant morphology through differential effects on cell division and expansion. The larger specific leaf area of wheat crop is associated with higher temperatures (Midmore *et al.,* 1984). The photosynthetic efficiency in C3 crops decreases almost linearly with temperature, mainly due to increased photorespiration. In contrast, wide temperature conditions remarkably show little variation in the C4 species (Ehleringer and Pearcy, 1983). In wheat crop, there is a close relation between the number of kernels per unit area and the ratio between incoming radiation to the mean temperature above 4.5°C (the photothermal quotient) calculated for the 30 days preceding anthesis (Fischer, 1985). Higher radiation increases the amount of photosynthates available for spike growth and lower temperatures prolong the period of spikelet growth and decrease competition for carbohydrates. In present study, the WOFOST (v 7.1) model was employed to assess the impact of altered duration of photoperiod (bright sunshine hour), maximum and minimum temperature (°C) on grain yield during different growth stages of wheat crop.

## MATERIALS AND METHODS

The field experiments were conducted in two consecutive *rabi* seasons during 2009-10 and 2010-11 at the research farm of the Department of Agrometeorology, AAU, Anand (Gujarat), India situated at latitude 22°35' N, longitude 72°55'E and at altitude of 45.1 m above mean sea level. The daily meteorological variables were collected from agrometeorological observatory situated near the experimental plot. The WOFOST (v 7.1) model calibrated and validated under four dates of sowing *viz.,* $D_1$- 1st Nov, $D_2$- 15th Nov., $D_3$-30th Nov and $D_4$-15th Dec. by Mishra *et al.* (2013) for cv. GW 322, GW 496, GW366 and GW 1139 was used for sensitivity analysis.

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The reference, optimum or base yield for all cultivars selected in this study was simulated by running the WOFOST model with daily normal weather data set following Kalra (2008). One variable at a time was modified and its effect was studied on growth and yield of cultivars however, all other variables were kept the normal as such (Hundal and Kaur, 2007). Hence, the obtained yield simulated for all cultivars were considered as reference or base yield. The potential condition was assumed with congenial weather and adequate management practices. For present study, the artificial climatic conditions were created by increasing and decreasing the bright sun shine hour from 0.5 to 2.5 hours and temperature (maximum and minimum) from 1.0 to 5.0 °C at different phenological stages (*viz.* tillering to booting, booting to flowering, flowering to milking, milking to dough and sowing to physiological maturity) of the crop.

## RESULTS AND DISCUSSION

### *Effects of bright sun shine hours*

The effect of change in sunshine hours by increasing and decreasing it at incremental rate of 0.5 hours on both side from the normal, during different stages of the crop as well as for whole life period of wheat are presented in Table 1 and Fig.1, respectively. It may be seen from the Table 1, that increase in sunshine hours during all different stages of the crop resulted in increased yield of all cultivars of wheat. Conversely, increase in sunshine hours decreased the yield. The extent of increase or decrease in yield however, differed with variety and stage of the crop. The crop cycle in the cereals is associated with a sequence of physiological events controlled mainly by temperature and photoperiod (Slafer and Rawson, 1994). Among the different stages of crop, milking to dough stage was found to be most sensitive to BSS, as the increase (20 to 28%) or decrease (-18 to 21%) are maximum in all the varieties with increase or decrease of 2.5 hours/ day. The tillering to booting stage was found to be least sensitive to change in BSS. Among the varieties, GW 322 was found least sensitive while, GW 1139 was found most sensitive in most of the stages of wheat. The wheat crop requires relatively higher photoperiod between flowering to milking stage to produce more flowers which ultimately affects the final production. Therefore, positive movement of photoperiod tends to increase production and *vice versa.* Photoperiod also increased the pre-anthesis radiation use efficiency and hence, more biomass at anthesis, resulting the more assimilates available to increase spike mass. Slafer *et al.* (1996) found that the relative duration of spike growth as well as spike mass was increased through the manipulation of photoperiod. Similarly, the increase or decrease of BSS during entire crop growing period (Fig.1), had also similar effect as observed in different phases with higher magnitude (30 – 40%) increase and (-24 to -27%) decrease.

### *Effects of maximum air temperature*

The sensitivity analysis of all wheat cultivars (Table 1) showed that downscaled maximum temperature increased the yield and *vice versa.* However, its effect was sensed differently among different cultivars and crop growth stages. The effect of increased temperature on grains yield of wheat may be attributed to the decreased number of fertile spikes along with the fewer grains per ear. The early wheat growth stages were comparatively less affected with changes in maximum temperature than later stages however, reproductive stages were most vulnerable. During tillering to booting stage, ± 5°C departure of maximum temperature changed the yield from -11.9 to 10.1%. Warrington *et al.* (1977) showed that under controlled experiment, during double ridges to anthesis stage, the wheat grown at 25°C, had only 40% of the kernel number in the main spike than crop grown at 15°C. Increase in maximum temperature by 5°C between booting to flowering stage, reduced the grain yield by 7.2 to 11.1%. During flowering to milking stage, ± 5°C deviation of maximum temperature from normal, highly affected the yield of GW 496 by -19.0 and 16.1%. During milking to dough stage, 5°C downscaled maximum temperature, increased the grain yield by 20.4% and 21.5% whereas, increased temperature by 5°C, reduced the yield by 23.8% and 30.1%. The losses in yield with rise in ambient temperature may be due to shortened phenological duration (Aggarwal and Sinha, 1993; Aggarwal and Kalra, 1994; Muchow *et al.*, 1997. During entire crop season, rise and fall of maximum temperature by 5°C decreased yield by 37.4% to 47.6% and 24.1% to 28.5%, respectively (Fig. 1). The effect of increased maximum temperature felt more in high yielding varieties (GW 322 and GW 496) whereas, GW 366 and GW 1139 were highly capable to adopt the changing temperature conditions. Pathak *et al.* (2003), on the basis of sensitivity analysis of CERES-Wheat also stated that elevated maximum temperature decreased wheat yield significantly. Akula (2003) has reported similar findings for WTGROWS and INFOCROP models for wheat (cv. GW-496).

### *Effects of minimum air temperature*

The high night temperature favour the accelerated

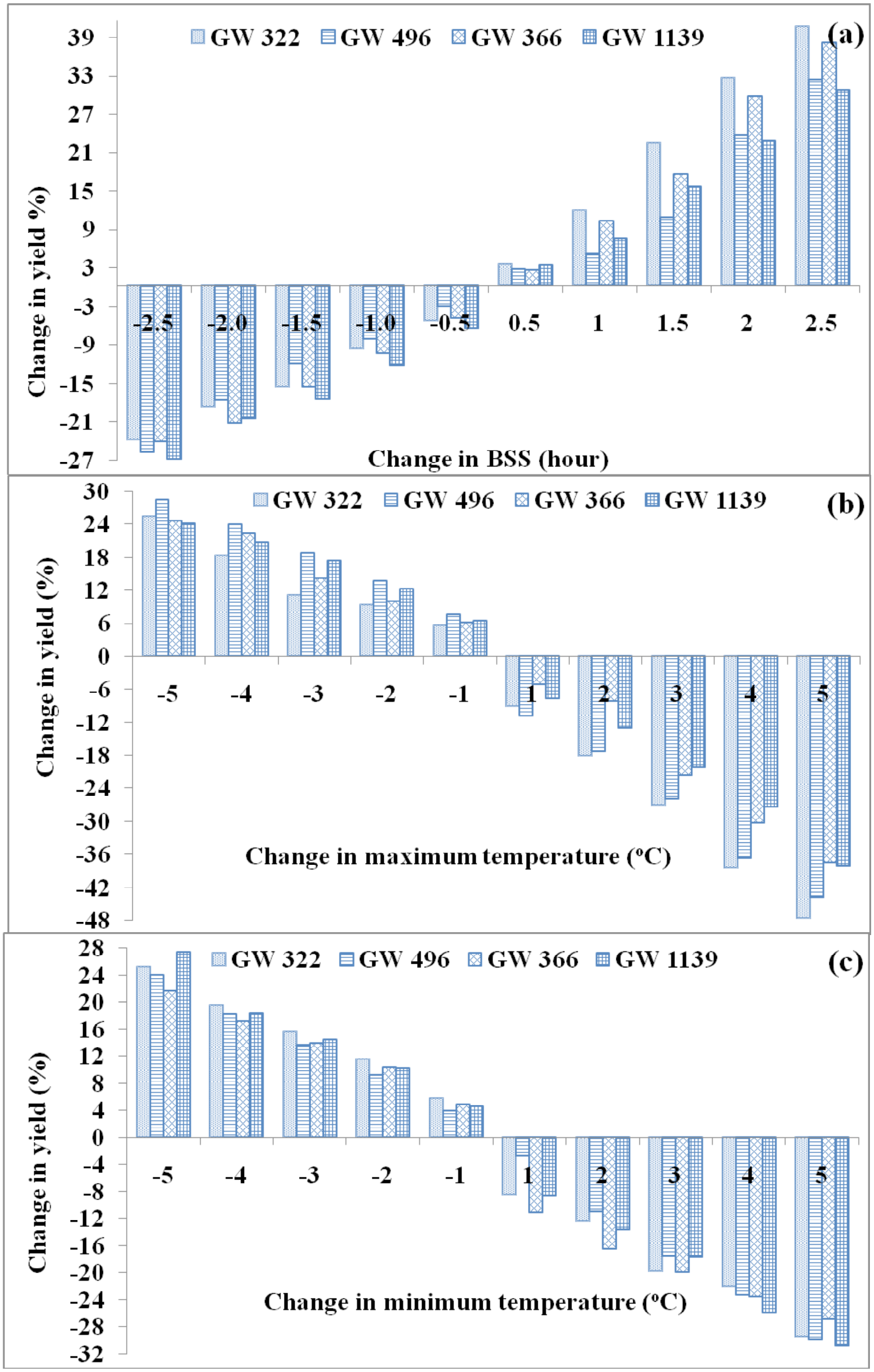


**Fig.1:** Effect of altered (a) BSS, (b) Tmax and (c) Tmin from sowing to maturity on grain yieldTable 1: Change in simulated grain yield (%) with altered photoperiod (hour) and temperature (°C) among different growth stages of wheat

Table 1: Change in simulated grain yield (%) with altered photoperiod (hour) and temperature (°C) among different growth stages of wheat

| | Tillering to Booting stage | | | | Booting to flowering stage | | | | Flowering to milking stage | | | | Milking to dough stage | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GW322 | GW496 | GW366 | GW1139 | GW322 | GW496 | GW366 | GW1139 | GW322 | GW496 | GW366 | GW1139 | GW322 | GW496 | GW366 | GW1139 |
| " BSS Change in simulated yield (%) | | | | | | | | | | | | | | | | |
| -2.5 | -8.7 | -8.1 | -10.7 | -11.3 | -9.5 | -9.3 | -9.4 | -12.9 | -14.6 | -14.5 | -14.8 | -17.0 | -18.0 | -19.8 | -19.6 | -21.4 |
| -2.0 | -7.2 | -6.6 | -7.0 | -8.3 | -6.7 | -6.1 | -5.8 | -9.2 | -11.1 | -10.2 | -11.4 | -12.8 | -15.8 | -14.1 | -16.9 | -17.0 |
| -1.5 | -4.3 | -3.9 | -3.9 | -4.7 | -4.0 | -3.2 | -3.1 | -6.0 | -8.1 | -6.4 | -7.6 | -9.5 | -11.8 | -12.5 | -14.5 | -12.8 |
| -1.0 | -1.9 | -1.3 | 1.9 | -2.0 | -2.8 | -1.5 | -2.4 | 2.5 | -5.0 | -3.7 | -3.7 | -4.0 | -8.2 | -10.3 | -8.6 | -9.5 |
| -0.5 | -0.9 | -0.4 | -1.0 | -1.0 | -1.4 | -0.6 | -1.6 | -0.6 | -2.8 | -1.4 | -2.6 | -2.8 | -3.8 | -6.0 | -4.2 | -2.8 |
| 0.5 | 0.4 | 0.9 | 0.5 | 1.5 | 1.4 | 1.5 | 1.6 | 2.9 | 1.7 | 1.6 | 1.5 | 2.5 | 5.6 | 6.9 | 2.3 | 2.5 |
| 1.0 | 2.3 | 2.3 | 2.3 | 2.9 | 3.4 | 3.0 | 3.5 | 4.3 | 5.8 | 3.4 | 5.3 | 4.8 | 8.7 | 10.0 | 5.9 | 4.8 |
| 1.5 | 4.2 | 4.7 | 4.8 | 5.2 | 5.3 | 5.5 | 5.9 | 6.6 | 9.8 | 7.0 | 9.3 | 9.1 | 13.0 | 16.4 | 9.5 | 9.5 |
| 2.0 | 7.8 | 7.9 | 8.1 | 9.6 | 8.9 | 8.7 | 9.2 | 11.0 | 14.0 | 13.4 | 13.8 | 14.4 | 19.2 | 20.8 | 13.1 | 16.4 |
| 2.5 | 9.6 | 10.4 | 10.6 | 12.3 | 10.6 | 11.0 | 11.7 | 13.7 | 15.4 | 17.8 | 17.5 | 18.8 | 28.5 | 24.4 | 20.3 | 23.9 |
| eTmax Change in simulated yield (%) | | | | | | | | | | | | | | | | |
| -5 | 10.1 | 9.6 | 8.8 | 8.2 | 10.7 | 10.3 | 9.4 | 9.0 | 13.5 | 16.1 | 14.3 | 15.3 | 16.6 | 21.5 | 20.4 | 13.3 |
| -4 | 8.0 | 6.8 | 6.4 | 5.6 | 8.6 | 7.5 | 7.1 | 6.4 | 11.2 | 12.8 | 11.9 | 12.3 | 13.2 | 12.8 | 16.2 | 10.5 |
| -3 | 5.2 | 4.5 | 4.0 | 4.0 | 5.8 | 5.2 | 4.6 | 4.8 | 7.9 | 9.5 | 7.6 | 9.3 | 9.8 | 9.5 | 11.9 | 8.4 |
| -2 | 2.3 | 2.3 | 2.7 | 2.8 | 2.9 | 3.0 | 3.4 | 3.6 | 4.8 | 6.3 | 5.4 | 6.2 | 6.3 | 6.3 | 7.6 | 6.2 |
| -1 | 1.2 | 1.5 | 1.0 | 1.2 | 1.8 | 2.2 | 1.7 | 2.0 | 2.9 | 3.8 | 3.0 | 3.2 | 2.9 | 3.8 | 3.0 | 3.2 |
| 1 | -1.4 | -1.9 | -1.1 | -2.7 | -0.8 | -1.2 | -0.4 | -1.9 | -2.2 | 3.4 | -2.2 | -4.1 | -9.1 | -6.1 | -2.3 | -7.1 |
| 2 | -2.0 | -2.8 | -2.8 | -4.0 | -1.4 | -2.1 | -2.1 | -3.2 | -5.5 | -7.4 | -4.3 | -6.7 | -17.1 | -10.7 | -4.3 | -11.5 |
| 3 | -4.0 | -3.4 | -4.4 | -6.8 | -3.4 | -2.7 | -3.7 | -6.1 | -8.5 | -10.7 | -9.9 | -9.4 | -21.3 | -15.4 | -14.1 | -19.6 |
| 4 | -7.1 | -5.5 | -6.4 | -9.1 | -6.5 | -4.8 | -5.7 | -8.3 | -11.2 | -14.6 | -14.1 | -13.4 | -26.0 | -19.9 | -20.1 | -21.5 |
| 5 | -10.2 | -8.7 | -7.8 | -11.9 | -9.6 | -8.0 | -7.2 | -11.1 | -16.1 | -19.0 | -17.5 | -17.1 | -29.6 | -23.8 | -26.4 | -30.1 |
| "Tmin Change in simulated yield (%) | | | | | | | | | | | | | | | | |
| -5 | 6.7 | 7.1 | 9.6 | 9.8 | 10.3 | 10.5 | 10.9 | 11.6 | 14.1 | 13.9 | 14.1 | 16.3 | 26.5 | 22.4 | 19.8 | 21.6 |
| -4 | 4.3 | 4.6 | 6.4 | 6.6 | 7.1 | 8.0 | 7.2 | 7.7 | 10.3 | 10.3 | 10.3 | 10.9 | 21.1 | 16.3 | 16.1 | 16.3 |
| -3 | 2.3 | 2.8 | 4.3 | 4.0 | 4.8 | 5.8 | 4.9 | 5.3 | 7.6 | 7.4 | 7.7 | 7.9 | 15.7 | 13.7 | 12.9 | 10.9 |
| -2 | 1.0 | 1.5 | 2.7 | 2.9 | 2.2 | 3.1 | 3.2 | 3.0 | 4.9 | 4.6 | 5.4 | 5.4 | 10.3 | 10.3 | 7.7 | 7.9 |
| -1 | 0.7 | 0.6 | 1.0 | 0.8 | 1.3 | 1.3 | 1.5 | 1.6 | 2.6 | 2.0 | 2.4 | 2.3 | 4.9 | 4.2 | 5.4 | 2.3 |
| 1 | -1.7 | -0.6 | -1.3 | -1.9 | -1.9 | -1.0 | -2.2 | -2.8 | -4.1 | -1.4 | -4.9 | -4.4 | -6.5 | -5.1 | -4.9 | -4.4 |
| 2 | -3.1 | -1.7 | -2.6 | -3.2 | -4.0 | -2.6 | -4.2 | -4.6 | -6.5 | -5.1 | -7.7 | -7.2 | -12.0 | -11.5 | -7.7 | -7.2 |
| 3 | -4.7 | -3.3 | -4.0 | -5.1 | -6.1 | -4.0 | -5.9 | -6.8 | -10.2 | -8.3 | -9.9 | -9.9 | -15.7 | -15.2 | -12.8 | -14.9 |
| 4 | -5.1 | -4.7 | -6.5 | -8.4 | -9.0 | -6.3 | -8.5 | -10.8 | -12.0 | -11.5 | -12.8 | -15.0 | -20.3 | -18.4 | -17.0 | -21.9 |
| 5 | -6.4 | -6.2 | -7.8 | -10.0 | -11.4 | -9.6 | -10.2 | -12.8 | -15.7 | -15.2 | -14.9 | -17.9 | -23.4 | -22.0 | -20.9 | -22.7 |

development shorter spike growth period, high respiration resulting the reduced spike growth and lesser grain number. Such behavior of minimum temperature affects the wheat yield adversely. During tillering to booting stage, increased minimum temperature by 1 to 5°C decreased the simulated yield from 0.6 to 10.0% (Table 1). From booting to flowering stage, 5°C rise in minimum temperature the extent of losses were 9.6% to 12.8%. In contrary, 5°C decrease in minimum temperature during flowering to milking stage, the yield was increased by 13.9 to 16.3%. Over the whole crop season, 1 to 5 °C increased minimum temperature reduced the grain yield by 8.7 to 30.8% (GW 1139) and 2.7 to 29.9% (GW 496). Behaviour of decreased crop yield with increasing temperature may be due to dual effects of higher rate of respiration during night time resulted into comparatively higher loss of photosynthates and differential reduction in crop duration of different wheat cultivars. The lower temperatures increased the yield in the all four genotypes of wheat, but not in the similar magnitude. Similar effects of increased and decreased temperature on wheat (cv. GW 496) yield have been reported at Anand by Patel and Shekh (2007).

The change in the yield due to change in environmental conditions significantly varies among the phenological stages and genotypes. The variation in the yield was high if the unsuitable conditions persist for longer period. Therefore, the change conditions from tillering to grain filling stage as well as over entire crop season decreased grain yield more than individual growth stages. Among different individual stages, reproductive (flowering and dough) stages were considerably affected with altered conditions. The response of changed environments varied from cultivar to cultivar. The results described that GW 322 was high vulnerable to increased minimum temperature whereas, GW 366 was least sensitive among all.

## CONCLUSION

The results of the study described the tolerance power of various wheat cultivars in relation to changed photoperiod and temperature conditions. At different phenological stages of crop, the rate of influence varied among different cultivars. The wheat crop requires relatively higher photoperiod during flowering to milking stage to produce more flowers and high production. Therefore, positive movement of photoperiod tends to increased production and *vice versa*. The cultivar GW 322 was most sensitive to increased photoperiod followed by GW 366, GW 496 and GW 1139. The crop condition from tillering to grain filling (dough) stages plays the key role in determining the final productivity. The impact of high maximum temperature stressed more to GW 322 followed by GW 496, GW 366 and GW 1139. The *durum* wheat cultivar was least vulnerable to maximum temperature besides, the GW 322 realized maximum. Maximum beneficial effect of 5°C decreased minimum temperature was found in GW 1139 followed by GW 496, GW 322 and GW 366. The *durum* type cultivar was high sensitive with minimum temperature than *aestivum* type cultivars. Among individual crop growth stages, all cultivars were more sensitive for changes in weather conditions at later stages than earlier pheno-phases. The altered weather conditions from tillering to dough (grain filling) also affected the crop largely. The crop was extremely vulnerable under changed weather conditions for entire crop season. The crop was more vulnerable under temperature deviation than photoperiod. Impact of changed weather conditions affected greatly between flowering to grain ripening stages of the crop. Hence, it may be concluded that high yielding wheat cultivars (GW 322 and GW 496) are highly vulnerable whereas, the GW 366 and GW 1139 have high adaptive capacity to sustain under changed environmental conditions.

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