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IMPACT OF ELEVATED TEMPERATURE AT DIFFERENT PHENOLOGICAL STAGES ON THE GROWTH AND YIELD OF WHEAT AND RICE

MANJU ZACHARIAS*, S.D. SINGH, S. NARESH KUMAR, R.C. HARIT AND P.K. AGGARWAL

Division of Environmental Sciences, Indian Agricultural Research Institute, 110 012, New Delhi, India

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SUMMARY

In this study we have evaluated the response of two cultivars of wheat (PBW-343 and Kundan) and rice (PS-2 and P-44) to high temperature stress. The stress was given either throughout crop growth period or at one of the three growth phases viz., seedling to panicle initiation, panicle initiation to flowering and flowering to maturity. Results indicated that the warmer temperature hasten crop development, shortens the growth period and thus finally lowers the grain yield in both crops. The impact of high temperature on crop growth and yield is largely determined by the duration and coincidence of it with sensitive crop growth phase. Period from panicle initiation to flowering stage was found to be more sensitive to high temperature stress in both wheat and rice. Exposure to high temperature from seedling stage to panicle initiation stage affected yield predominantly due to associated tiller mortality and reduced number of spikes. Coincidence of high temperature stress with panicle initiation to flowering phase of crop affect grain yield by reducing dry matter accumulation, productive tillers, number of spikes, grain weight and increased floret sterility. When the crop is exposed to heat stress from flowering to maturity, then the reduction in yield is predominantly caused by floret sterility leading to reduced number of grains per spike and also due to reduced grain weight. Among the varieties, Kundan of wheat and PS-2 of rice were found to be more tolerant to heat stress.

Keywords: **Climate change, high temperature, rice, sensitive growth phase, wheat**

INTRODUCTION

According to IPCC (2007), global earth temperatures have increased by 0.74^0C during twentieth century, and are likely to increase by 1.1 to 6.4^0C by 2100. It is uncertain whether future global climates of warmer temperatures will be more variable or not (Nicholls *et al.* 1996), but current warm temperature stress events will be more frequent for a given location even if the amplitude of temperature remains the same. Climatic variability and occurrence of extreme events are major concerns for India. IPCC and some other global studies indicate considerable probability of loss in crop production in India with increases in temperature and some of these projected loss estimates for the period of 2080-2100 are 5 to 30% (Fischer *et al.* 2002, Parry *et al.* 2004, IPCC 2007). Crop productivity is projected to decrease for even small local temperature increases (1-2^0C) at lower latitude, especially seasonal dry and tropical regions, which would increase the risk of hunger (IPCC, 2007).

Various studies demonstrate that variability in temperature affects the grain and seed yield of annual crops (Semenov and Porter 1995, Mearns *et al.* 1997, Batts *et al.* 1997). Coincidence of high temperature with

*Corresponding author: E-mail: zacmanju@gmail.com

sensitive stage or phases of rice and wheat crops could cause severe yield loss (Rawsan and Bagga 1979, Yoshida 1981, Shpiler and Blum 1986, Stone and Nicolas 1994, Ferris *et al.* 1998, Gibson and Paulsen 1999). Long duration of exposure to moderately high temperature as well as short duration to very high temperature reduces wheat yield. Warmer temperature hastens the crop development and shortens the growth period (Sadras and Monzon 2006, Tao *et al.* 2006, Challinor and Wheeler 2008). Even a brief period of exposure to high ambient temperature (>35°C) can drastically reduce the grain yield in wheat (Randall and Moss 1990 and Stone and Nicolas 1994). Heat shock at the end of tillering strongly reduced the rate of leaf photosynthesis while during grain filling decreased both rate of photosynthesis (source) and grain growth (sink) (Egli 2004, Schapendonk *et al.* 2007, Yang *et al.* 2008). Simulation studies using InfoCrop model showed that increase in temperature may decrease wheat production in India (Aggarwal and Rani 2009). Similarly in rice also, very high temperatures during reproductive stage induce spikelet sterility there by affect the seed setting and consequently reduce yield (Cao *et al.* 2009, Matsui 2001). In case of rice, simulated yield potential in major rice growing regions of Asia may decrease by 7% for every 1^0C rise above the current mean temperature (Matthews *et al.* 1997).

Since climatic change is projected to bring about mean changes in climatic parameters as well as increase in frequency of extreme events, it is important to quantify the differential impacts of short-term temperature rise on crop growth, development and productivity. The present study was therefore undertaken with the objective to assess the growth and yield performance of wheat and rice subjected to high temperature at different growth phases.

MATERIALS AND METHODS

A pot experiment was conducted in completely randomized design (CRD) with five replications in the Glasshouse premise of Environmental Science division, Indian Agricultural Research Institute, New Delhi during the *kharif* and *Rabi* seasons of 2007-08 and 2008-09. Two promising varieties each of rice (Pusa Suganth-2 and Pusa-44) and wheat (PBW-343 and Kundan) were grown in plastic crates (60 x 45 x 30 cm size) and managed with normal agronomic practices. After germination of wheat and seedling establishment of rice, the crates were divided into five sets comprising both the cultivars of wheat and rice. Five thermal treatments were created and plants were subjected to high temperature stress during different growth phases i.e. seedling emergence to panicle initiation (T1), panicle initiation to flowering (T2), flowering to maturity (T3), seedling to maturity (T4). Apart from above, a set of plants was grown at ambient temperature from seedling to maturity which served as control (T0). High temperature stress was imposed by covering the plants with portable transparent polythene chamber of 2 m x 2 m x 2 m size. To maintain the same level of radiation and temperature at par to ambient in control set, it was covered partially with polythene sheet. Daily maximum and minimum temperature and relative humidity in control as well as treatment blocks were recorded throughout the growing season.

Growth observations were recorded at 50% flowering and yield and yield attributes at maturity. Percentage of productive tillers was calculated from the number of panicle bearing tillers to maximum number of tillers produced. Indirectly, it refers to the tiller mortality percentage. Percentage of spikelet sterility was calculated from the number of unfilled spikelets to the total number of spikelets. Similarly, harvest index (HI) was calculated from the ratio of grain yield to total above ground biomass. All data were analyzed using general linear model in SPSS (v 16.) statistical package.

RESULTS AND DISCUSSION

Response of wheat to elevated temperature: Based on the experiments conducted during *Rabi* season for two years, it was found that the year 2007 (year I) was more favorable for the crop growth. Analysis indicated that temperatures of that year were lower compared to that of 2008 (year II). The mean ambient temperature in 2007 during the growing season was 16.3^0C with a mean maximum of 24.1^0C and mean minimum of 8.6^oC, while in 2008, the mean temperature was 17.3^oC with the average maximum temperature was 24.7^oC and mean minimum temperature was 9.8^oC. Thus the temperatures were high by about 1^oC for seasonal mean temperature, by 0.6^oC for seasonal mean maximum temperature and by 1.2°C for seasonal mean minimum temperature (Table 1).

Apart from these, there existed variation for temperature during different phase of crop growth during the growing season (Table 1). Results indicated that high temperature caused hastening of flowering and maturity in wheat. However, degree of response varied according to the time, duration and intensity of increase in temperature (Table 2). For instance, wheat crop grown at elevated temperature throughout growing season had flowered earliest and also matured early. Similarly, exposure to high temperatures up to spike initiation stage also caused earliness in flowering and maturity, but the reduction in duration to flowering and maturity was lesser as compared to that in plants exposed to high temperature throughout their life cycle. High temperatures coinciding with spike initiation to flowering stage of crop also caused earliness in flowering, but with lesser degree. Increase in temperature during post-anthesis, reduced the grain filling period. Results also indicated that the impact of high temperatures on reducing the crop growth period was almost half if it was exposed to high temperatures for same period during pre-flowering phase. Crop duration was, in general, less in the second year of experiment further confirming the effect of higher temperature on the growth duration of the crops.

High temperature throughout the crop growth period i.e. from seedling to maturity severely affected the growth and yield in wheat. A reduction in dry matter accumulation, increased tiller mortality (thus reduced number of productive tillers) along with reduced number of spikes and spikelets and grain weight caused reduction in grain yield (Table 2 and Fig. 1). High temperatures also increased floret sterility and reduced dry matter partitioning to grain as indicated by reduced harvest index (Fig. 1).

Impact of high temperature on wheat crop depends on the coincidence of heat stress with sensitive phases of crop growth. Overall reduction in crop performance in terms of dry matter accumulation, number of

Table 1. Mean maximum and mean minimum temperature during different phenological phases of rice and wheat under various treatments.

Crop	Treatments	Seedling-Panicle initiation				Panicle initiation-Flowering				Flowering-Maturity			
		I year		II year		I year		II year		I year		II year	
		Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Wheat	T0	20.01	5.35	21.05	7.45	23.97	8.18	25.48	10.07	31.83	15.15	30.23	13.94
	T1	22.89	6.12	23.9	8.62	23.97	8.18	25.48	10.07	31.83	15.15	30.23	13.94
	T2	20.01	5.35	21.05	7.45	26.77	9.08	28.46	11.58	31.83	15.15	30.23	13.94
	T3	20.01	5.35	21.05	7.45	23.97	8.18	25.48	10.07	34	16.20	33.09	15.43
	T4	22.89	6.12	23.9	8.62	26.77	9.08	28.46	11.58	34	16.20	33.09	15.43
Rice	T0	34.07	26.17	34.64	25.94	33.61	22.38	33.70	23.17	31.97	13.88	32.72	16.35
	T1	37	28.4	37	28.65	33.61	22.38	33.70	23.17	31.97	13.88	32.72	16.35
	T2	34.07	26.17	34.64	25.94	36.92	24.49	36.23	25.84	31.97	13.88	32.72	16.35
	T3	34.07	26.17	34.64	25.94	33.61	22.38	33.70	23.17	35.49	16.4	35.23	19.3
	T4	37	28.4	37	28.65	36.92	24.49	36.23	25.84	35.49	16.4	35.23	19.3

Tmax- Mean maximum temperature
Tmin- Mean minimum temperature
T0- Plants grown under ambient temperature from seedling to maturity
T1- Plants grown under high temperature from seedling to panicle initiation
T2- Plants grown under high temperature from panicle initiation to flowering
T3- Plants grown under high temperature from flowering to maturity
T4- Plants grown under high temperature from seedling to maturity

Table 2. Effect of increase in temperature during different phenological phases on growth and yield of wheat

Variety/ Treatment	Days to anthesis	Days to maturity	Dry weight of stem (g)	Dry weight of leaf (g/pot)	Total dry weight (g/pot)	Tiller mortality (%)	Number of spikes/pot	No. of grains/ spike	Grain yield (g/pot)
PBW 343									
T0	87	117	69.6	19.0	207.7	18.7	66.5	57.5	83.6
T1	85	114	56.1	22.3	195.0	22.1	56.5	57.0	77.8
	(-2)	(-3)	(-19.4)	(17.3)	(-6.1)	(3.4)	(-15.0)	(-0.9)	(-7.0)
T2	84	112	58.2	16.5	190.1	21.6	59.0	44.5	72.8
	(-3)	(-5)	(-16.5)	(-13.2)	(-8.5)	(2.9)	(-11.3)	(-22.6)	(-12.9)
T3	87	115	62.2	15.5	194.2	20.0	62.5	47.0	74.8
	(0)	(-2)	(-10.7)	(-18.4)	(-6.5)	(1.3)	(-6.0)	(-18.3)	(-10.6)
T4	82	108	54.8	15.2	177.2	23.9	52.5	40.5	65.6
	(-6)	(-9)	(-21.3)	(-20.0)	(-14.7)	(5.2)	(-21.1)	(-29.6)	(-21.6)
KUNDAN									
T0	82	113	66.5	17.5	212.1	17.3	61.0	50.5	91.3
T1	78	111	53.5	19.8	194.9	23.8	55.0	50.5	82.3
	(-5)	(-2)	(-19.6)	(13.1)	(-8.1)	(6.5)	(-9.8)	(0.0)	(-9.9)
T2	79	110	60.5	15.8	177.8	20.6	57.0	42.0	70.7
	(-4)	(-3)	(-9.0)	(-9.8)	(-16.2)	(3.2)	(-6.6)	(-16.8)	(-22.6)
T3	82	112	65.8	15.2	188.0	19.5	60.5	46.5	75.5
	(0)	(-1)	(-1.1)	(-13.2)	(-11.4)	(2.2)	(-0.8)	(-7.9)	(-17.3)
T4	76	105	52.5	15.0	168.2	24.7	51.0	37.5	65.0
	(-6)	(-8)	(-21.0)	(-14.4)	(-20.7)	(7.4)	(-16.4)	(-25.7)	(-28.8)

T1: Plants grown under high temperature from seedling to spike initiation
T2: Plants grown under high temperature from spike initiation to flowering
T3: Plants grown under high temperature from Flowering to maturity
T4: Plants grown under high temperature from seedling to maturity

productive tillers, number of spikes, number of grains per spike, grain weight and thus yield was noted when crop was exposed to high temperature for entire life cycle. However, when crop was exposed to high temperature for same period of life cycle, the responses were specific. For instance, exposure to high temperature from seedling stage to panicle initiation stage affected yield predominantly causing tiller mortality and reduced number of spikes. On the other hand, coincidence of high temperature stress with spike initiation to flowering phase of crop affected grain yield by reducing dry matter accumulation, productive tillers, number of spikes, number of grains per spike and grain weight. In case crop is exposed to heat stress during grain filling period, then the reduction in yield is predominantly caused by floret sterility leading to reduced number of grains per spike and also due to reduced grain weight.

Results also indicated that the spike initiation to flowering phase was the most sensitive stage to high temperature stress followed by grain filling period, while the seedling to panicle initiation phase was the least sensitive phase. Among the two varieties, Kundan performed better than PBW-343 under various temperature treatments, in spite of recording higher losses compared to control (Table 2 and Fig. 1).

Response of rice to elevated temperature: For rice growing season, the mean temperature during the first year was 27.6^{0}C with a mean maximum of 33.4^{0}C and

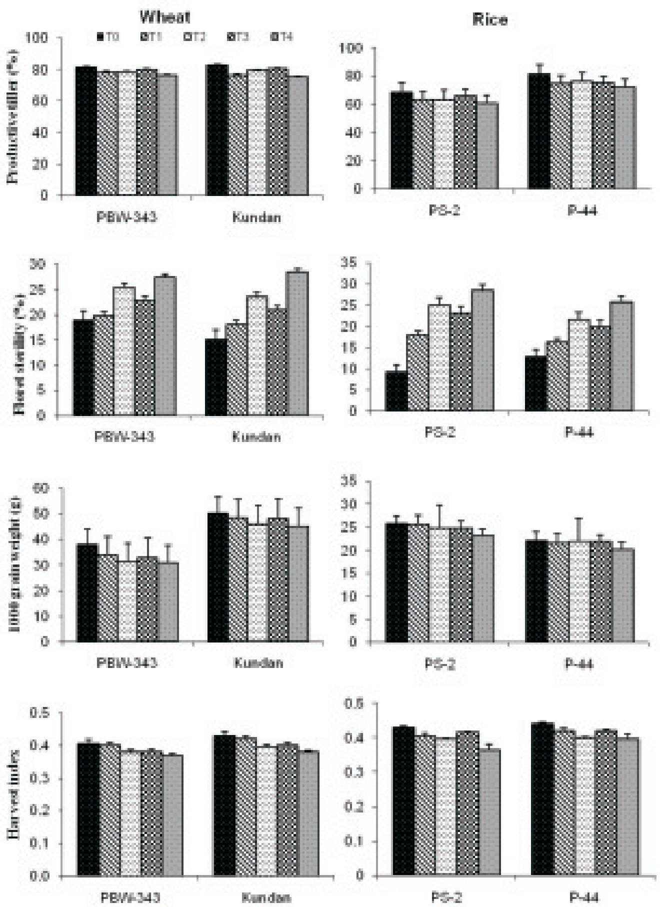

Fig. 1. Effect of increase in temperature during different phenological stages on yield components of wheat and rice. T1- Plants grown under high temperature from seedling to panicle initiation,T2- Plants grown under high temperature from panicle initiation to flowering, T3- Plants grown under high temperature from flowering to maturity, T4- Plants grown under high temperature from seedling to maturity

mean minimum of 21.8^{0}C, while the values were 28.4, 33.9, 22.9^{0}C, respectively during the second year (Table 1). High temperature caused early flowering in rice and this impact was similar when the crop was exposed to high temperature throughout its life cycle or only up to panicle initiation stage. High temperature stress from panicle initiation on wards did not shift flowering time, but reduced grain filling period. Likewise, plants grown under high temperature from seedling to maturity stage reached maturity faster than those in other treatments. Exposure of rice to high temperature up to panicle initiation stage reduced more of vegetative duration whereas exposure during post-panicle initiation stage of crop predominantly reduced the grain filling period.

In rice also, high temperature stress caused reduction in total dry matter, tiller mortality, reduced the number of panicles, grain per panicle, floret sterility and grain weight thus reducing the grain yield. However, coincidence of high temperature stress with early growth phase (up to panicle intimation stage) of transplanted rice caused yield reduction mainly due to tiller mortality (Fig. 1). On the other hand, high temperature stress during panicle initiation to flowering caused yield reduction mainly due to reduced dry matter accumulation and floret sterility (Fig. 1). High temperature stress during grain filling period reduced yield predominantly by affecting the dry matter accumulation, floret sterility and grain weight. Panicle initiation to flowering period and grain filling duration was found to be more sensitive to high temperature stress (Table 3 and Fig. 1).

The highest tiller mortality was caused in plants grown under high temperature from seedling to maturity and followed by plants grown under high temperature from seedling to panicle initiation and those exposed to high temperature from panicle initiation to flowering. Among the varieties the highest tiller mortality was observed in PS-2, whereas the spikelet sterility due to high temperature treatments was found to be higher in PS-2 than in P-44. However, PS-2 had a marginal advantage under high temperature stress conditions (Table 3 and Fig. 1).

Based on the above results it has been found that the plants subjected to high temperature throughout the crop growth and those grown at high temperature from seedling to panicle initiation flowered earlier than those in other treatments. Likewise the plants subjected to high temperature throughout the crop growth period reached maturity faster than others in both rice and wheat. These results indicate temperature as the main driving force for crop duration and at higher temperatures the fulfillment of thermal time for phenological stage was faster. Several earlier studies also reported that warmer temperature hastens the crop development, shortens the growth period (Challinor and Wheeler 2007, Sadras and Monzon 2006, Tao *et al.* 2006). However, current study indicates that the relative impact on high temperature on crop phenology depended on the time of occurrence of high temperature during crop growth phases.

Table 3. Effect of increase in temperature during different phenological phases on growth and yield of rice

Variety/ Treatment	Days to anthesis	Days to maturity	Dry weight of stem (g)	Dry weight of leaf (g/pot)	Total dry weight (g/pot)	Tiller mortality (%)	Number of panicles/pot	No. of grains/ panicle	Grain yield (g/pot)
Pusa Sugandh-2									
T0	99	132	85.3	74.7	338.8	20.3	91.5	61.0	145.4
T1	94	127	87.2	74.4	322.4	30.0	77.0	54.5	130.1
	(-6)	(-5)	(2.2)	(-0.4)	(-4.8)	(9.8)	(-15.8)	(-10.7)	(-10.5)
T2	97	125	75.4	71.4	301.7	26.1	80.5	43.5	119.9
	(-2)	(-7)	(-11.6)	(-4.4)	(-10.9)	(5.8)	(-12.0)	(-28.7)	(-17.6)
T3	99	130	74.8	67.3	305.6	22.7	90.0	49.5	126.1
	(0)	(-2)	(-12.4)	(-9.9)	(-9.8)	(2.4)	(-1.6)	(-18.9)	(-13.3)
T4	93	124	63.1	55.5	290.4	31.3	75.5	39.0	106.5
	(-7)	(-8)	(-26.1)	(-25.7)	(-14.3)	(11.1)	(-17.5)	(-36.1)	(-26.7)
PUSA 44									
T0	102	136	94.3	91.5	318.4	11.5	80.5	52.5	139.4
T1	99	131	88.6	87.2	298.1	22.1	72.5	49.5	123.8
	(-4)	(-6)	(-6.0)	(-4.7)	(-6.4)	(10.6)	(-9.9)	(-5.7)	(-11.2)
T2	102	129	83.9	88.5	282.3	17.8	74.5	36.5	112.7
	(-1)	(-7)	(-11.0)	(-3.3)	(-11.3)	(6.4)	(-7.5)	(-30.5)	(-19.2)
T3	103	133	81.2	83.2	283.3	18.5	77.0	42.0	118.3
	(1)	(-4)	(-13.8)	(-9.0)	(-11.0)	(7.0)	(-4.3)	(-20.0)	(-15.1)
T4	97	126	74.2	63.8	269.0	22.8	70.0	31.0	105.4
	(-5)	(-11)	(-21.2)	(-30.3)	(-15.5)	(11.4)	(-13.0)	(-41.0)	(-24.4)

T1: Plants grown under high temperature from seedling to panicle initiation
T2: Plants grown under high temperature from panicle initiation to flowering
T3: Plants grown under high temperature from Flowering to maturity
T4: Plants grown under high temperature from seedling to maturity

High temperature stress throughout plant growth period or even during early growth phase up to panicle initiation caused the highest reduction in productive tiller percent. In these situations the tillering might have affected due to reduced availability of photosynthates and inter-tillers competition for the resources for their growth. Reduction in tiller number due to increased mortality of tillers owing to the intense competition for the limited resources was reported. His study also indicated a temperature driven shift in biomass partitioning in rice and wheat. For instance, in plants exposed to high temperature up to panicle initiation stage, biomass was preferably partitioned into leaves in case of wheat. In rice, partitioning was more towards culm, even though it was not significant. This clearly indicates that high temperature during the vegetative phase causes faster growth rates leading to greater leaf area. Under these situations, plants, provided with ample nutrients and water, can reduce the impact of initial heat stress as observed in this experiment.

The detrimental effect of high temperature on the grain yield of cereal crops were mainly attribute to the marked reduction in their yield components such as number of spikes or panicles, number of spikelets per spike, number of grains per spike or panicle and 1000 grain weight. Shortening of growth duration particularly vegetative growth duration by high temperature results in less number of spikes or panicles per plant and the reduction in productive tiller percentage as discussed earlier. The high temperature hastens physiological maturity and thus decreases the partitioning of photosynthates to grains (Morita *et al.* 2005). Plant maintenance respiration increases with increasing temperature (Amthor 2001, Guo *et al.* 2006) and at a greater rate of maintenance respiration decreased the amount of assimilates available for growth and yield (Mohammed and Tarpley 2009, Turnbull *et al.* 2002, Vagen *et al.* 2003). High temperature at anthesis decrease yield (Challinor *et al.* 2005) and the reduced yield may be due to the high spikelet sterility (Krishnan and Rao 2005, Sheehy 2007) or because of the lower grain weight. In the current experiment we observed the higher sterility of spikelets in plants which subjected to high temperature all through the life cycle and those which grown at high temperature from panicle initiation to flowering and flowering to maturity. And these treatments were showing the lowest grain weight too. Plants exposed to high temperature stress during anthesis had low yield due to the reduction in grain number as reported earlier in wheat (Ferris *et al.* 1998). Heat-induced spikelet sterility was linked to decreased anther dehiscence, poor shedding of pollen, poor germination of pollen grains on the stigma and decreased elongation of pollen tubes in rice (Prasad *et al.* 2006).

Coincidence of high temperature from flowering to maturity caused reduction in grain filling period resulting in to low yield which is a major limitation on wheat yields. Furthermore seed-filling rate is highly dependent on temperature (Egli 2004, Yang *et al.* 2008) and the grain filling is found to be seriously impaired by heat stress due to reductions in current leaf and ear photosynthesis at high temperature (Blum *et al.* 1994). Various studies revealed that, with the increase of temperature and its duration, seed-setting rate in rice decreased (SHI *et al.* 2008) causing yield loss. The later stages of cell division and enlargement in the grain occur after anthesis (Royo *et al.* 2000, Calderini and Reynolds, 2000) and appear to be particular sensitive to high temperature (Wardlaw and Wrigley 1994) and hence any increase in temperature during that period will be deleterious to yield. The grain weight was found to be in the lower side in this treatment and this may be because of the high temperature which cause the shriveling of the grains and thus reduce the grain weight. The high temperature before anthesis resulted in low grain number while its occurrence after anthesis caused yield loss by reducing the grain weight (Ugarte *et al.* 2007).

Even though biomass production is a clear indication of economic produce, the translocation of assimilates from source to sink place a pivotal role in grain yield determination. High temperature stress also affect the partitioning of biomass from vegetative to reproductive organs with clearly evident from the results of reduced harvest index under high temperature conditions. In this study results proved that the plants which were growing at high temperature all through and those subjected to high temperature from panicle initiation to flowering had reduced harvest index. The reduction in the biomass was relatively more than that of grain yield under high temperature stress causing reduced harvest index.

It can be concluded that the warmer temperature hastens crop development, shortens the growth period and thus finally lowers the grain yield. Impact of high temperature on crop growth and yield is largely determined by the duration and coincidence of it with sensitive crop growth phase. Period from panicle initiation to flowering stage is found to be more sensitive to high temperature stress in wheat and rice. Exposure to high temperature from seedling stage to panicle initiation stage affected yield predominantly causing tiller mortality and reduced number of spikes. Coincidence of high temperature stress with panicle initiation to flowering phase of crop affect grain yield by reducing dry matter accumulation, productive tillers, number of spikes, grain weight and increased floret sterility. In case crop is exposed to heat stress from flowering to maturity, then the reduction in yield is predominantly caused by floret sterility leading to reduced number of grains per spike and also due to reduced grain weight.

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