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Effect of Water Stress and Heat Stress on Crop Phenology, Yield and Yield Attributes of Rice (*Oryza Sativa* L.)

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ABSTRACT

The impact of water stress (Ws), high temperature (Ht) and combined water stress + high temperature stress (Ws+Ht) on phenological parameters, yield and yield attributes of four rice genotypes (Rasi, ADT43, N22 and Vandana) was studied. Plant height increased in response to Ht and reduced marginally in Ws and Ht+Ws. Compared to control, there was a decrease in the number of days to 50% flowering and days to maturity under Ht (10 and 14 days respectively) and Ht+Ws (11 and 16 days respectively). Ws, Ht and their interaction led to a reduction in grain yield and all the yield attributes. The reduction was higher in combined stress than individual stresses. Rasi recorded maximum panicle weight, number of grains panicle^{-1} and filled grains panicle^{-1} under all stress conditions. Filled grains panicle^{-1} were low in MTU1001 under Ws, Ht and Ht+Ws. Spikelet fertility was maximum under Ws in Rasi and in Ht and Ht+Ws in N22 while, minimum was in Vandana under Ht and in MTU1001 under Ws and Ht+ Ws. The highest 1000 grain weight in Ws, Ht and Ht+Ws was in Rasi and the lowest in Ws was in MTU1001, in Ht and Ht+Ws in Vandana. In Ws, Ht and Ht+Ws maximum and minimum grain yield was noted in Rasi and Vandana respectively.

Key words: *High temperature, Rice, Spikelet fertility, water stress, yield.*

Rice (*Oryza sativa*) is an important staple food for more than 50 percent of the world's population (Sarkar *et al*., 2009). The over exploding population is demanding an increase in the rice production. Hence, increase in the rice production is the current pre-requisite. India is potentially vulnerable to adverse impacts on agriculture on account of climate change which influence the yields of crop to a great extent. One of the major reasons for decrease in rice yields is the negative impact of climate change. Water stress and high temperature stress are among the two most important environmental factors influencing crop growth, development, and yield processes.

Crops are generally more sensitive to water stress and/or high temperature stress during reproductive stages of development which mainly influence the phenological development, growth, yield components and ultimately results in reduced yields. The reproductive stage in rice is affected irreversibly by high temperature (Prasad *et al*., 2006) and water stress (Liu *et al*., 2006) than the vegetative stage. Both water stress and heat stress influence an array of processes including physiological, growth, developmental, yield and quality of crop.

Water stress mainly influences yield by limiting grain numbers by either influencing the amount of dry matter produced by the time of flowering or by directly influencing pollen or ovule function, which leads to decreased seed-set. Secondarily, it influences grain filling mainly by limiting the assimilate supply, leading to smaller grain size and lower yields.

High temperature also influences yields by reducing the number of grains by having an adverse impact on pollen viability or ovule function resulting in lower seed-set. High temperature stress also directly influences grain-filling duration leading to smaller grain size and ultimately lower yields. High temperature and drought increase the number of unfilled grains in the panicle. A considerable reduction in the spikelet fertility due to both the stresses also has been reported.

Hence an understanding of the influence of water stress and high temperature stress will be critical in evaluating the impact of climate change on rice production. Considering that high temperature and water stress strongly affect rice, this study was conducted to evaluate the impact of water stress, high temperature stress and combined water and high temperature stress on yield and yield components in Rice.

MATERIAL AND METHODS

A pot culture experiment was conducted in *kharif* 2015-16 at ICAR- Indian Institute of Rice Research to study the impact of water stress, high temperature stress and the interaction of high temperature and water stress in four rice genotypes (Rasi, ADT43, N22 and Vandana). During the crop growth period the mean monthly maximum temperature ranged from 32.3°C to 33.8°C with an average of 32.8°C. The mean minimum temperature ranged from 17.8°C to 23.3°C with an average of 20.6°C. Whereas, in the polyhouse, the average mean maximum temperature was 40.1°C and mean minimum

temperature was 23.5°C. The mean RH (I) and RH (II) in ambient conditions was 83.4% and 59.7%, respectively and in polyhouse it was 87.0% and 64.0%, respectively.

The pots (12" diameter) were filled with soil (clayey vertisol) and recommended nitrogen (N), phosphorus (P) and potassium (K) (100:60:40) were applied based on soil weight in each pot. Entire P, K and 1/3rd of N were applied as basal dose. Remaining N was applied in two equal splits, one at tillering and the other at booting stage. The experiment was laid out in a factorial randomised block design with 4 treatments, control (ambient conditions), water stress (in ambient conditions), high temperature (in polyhouse) and high temperature + water stress (in polyhouse). All the genotypes were sown and transplanted after 21days. Each genotype was transplanted in four sets in triplicates. One week after transplanting, two sets of every genotype were shifted into the polyhouse and exposed to high temperature. At maximum vegetative stage and one week after anthesis, irrigation was stopped and water stress was imposed to one set inside the polyhouse which served as high temperature combined with water stress treatment and outside which was considered as water stress treatment. Water stress was imposed upto 10 days during which need based water was added to water stress treated pots. Normal irrigation was resumed upto maturity after the stress was released.

Observations were recorded for various phenological parameters and yield attributes from the sampled plants tagged in each treatment and genotype. Plant height on tagged plants was recorded at maximum vegetative and reproductive stages by measuring the height from base of the plant to the tip of the terminal leaf or panicle on main stem and was expressed in centimeters (cm). The number of days taken for 50 per cent of plants to flower in each genotype and each treatment was noted as days to 50% flowering and was expressed in days. The number of days taken from sowing to physiological maturity was recorded and was expressed in days. At harvest, panicles from each treatment and genotype were harvested, sun dried and panicle weight was recorded and expressed in g hill^{-1}. The total grains were separated from the panicle and were counted using seed counter and expressed as number of grains panicle^{-1} and further separated into filled and unfilled grains and the filled grains were counted using seed counter and were expressed as number of filled grains panicle^{-1}.

Spikelet fertility was calculated as the number of filled spikelets/ total number of spikelets x 100 and expressed in per cent. A lot of grains were drawn at random from each treatment and each genotype in three replications, put in a seed counter and thousand grains were separated. The weight of thousand grains was recorded and expressed in g. At maturity, panicles in each treatment and genotype were harvested and grain yield was recorded and expressed in g plant^{-1}. The ratio of economic yield to total biological yield x 100 was computed as harvest index and expressed in %. Two way analysis of variance (ANOVA) was performed using Statistix 8.1 package. Statistical significance of the parameter means were determined by performing Fisher's LSD test to test the statistical significance.

RESULTS AND DISCUSSION

Effect of water stress and heat stress on phenological traits plant height (cm)

In vegetative and reproductive stages, when compared to control, imposition of water stress led to the marginal reduction in plant height of all the genotypes (Table 1). However in high temperature conditions, the plant height increased. The combined heat and water stress treatment led to an increase in mean plant height in vegetative stage but a reduction in reproductive stage. In vegetative stage, among the genotypes, maximum plant height was recorded in Vandana (83.2 cm) and minimum in Rasi (75.2 cm). In control (C), water stress (Ws) treatment, high temperature (Ht) and combined heat and water stress (Ht+Ws) treatment Vandana recorded maximum plant height (83.1, 82.4, 83.3 and 83.5 cm respectively). Minimum plant height in C and Ws was in N22 (72.7 and 72.4 cm respectively). In Ht and Ht+Ws it was minimum in MTU1001 (80.6 and 80.3 cm respectively). In reproductive stage, maximum and minimum plant height was noted in Vandana (101.3 cm) and MTU1001 (85.4 cm) respectively. Maximum plant height in all the conditions (C, Ws, Ht and Ht+Ws) was recorded in Vandana (104.0, 100.7, 107.0 and 93.7 cm respectively). Minimum plant height was in MTU1001 in C (84.6 cm) and Ws (82.3 cm) and in Rasi in Ht (88.1 cm) and Ht+Ws (84.5 cm).

Plant height is affected by both water stress and high temperature conditions. Drought reduced the plant height in spring maize by 28.9% (Ji *et al*., 2012). The reduction in plant height could be attributed to decline in the cell enlargement under water stress. Reduced plant height in response to drought stress was also reported by Sokoto and Muhammad (2014). In the present study also, there was a reduction in plant height in both the stages. Poli *et al*. (2013) reported an increase in plant height under high temperature than under ambient temperature condition which is similar to that observed in this study. In okra, individual effects of both water stress and temperature stress and their combination had significant effects on plant height. Water stress led to reduction in the plant height

however, higher temperature led to an increase (Gunawardhana and de Silva, 2011).

Days to 50% flowering

There was decrease in the number of days to 50% flowering due to high temperature and high temperature combined with water stress treatment (Table 2). Water stress treatment did not lead to significant change in days to 50% flowering. The mean number of days to 50% flowering reduced from 80 days to 70 days from C to Ht and to 69 days in Ht+Ws. Minimum reduction in days to 50% flowering from C to Ht and from C to Ht+Ws was in N22 (5 and 6 days respectively) and maximum in Vandana (13 and 15 days, respectively).

Days to maturity

Significant decrease in days to physiological maturity was also observed under elevated temperature stress and combined Ht+Ws treatments with respect to control. The mean days to maturity reduced from 107 days in C to 104 days in Ws, 93 days in Ht and to 91 days in Ht+Ws. Maximum decrease in days to maturity was noted in Vandana and MTU1001. Minimum decrease was noted in N22 (Table 2).

The flowering and maturity of all the tested rice varieties was found to be 5 to 14 days earlier under high temperature stress and the duration of the crop became shorter by 6 to 12 days than those at control condition. It might be attributed due to the faster vegetative growth and development that high temperature stress might have caused (Hazra *et al*., 2016).

Effect of water stress and heat stress on yield and yield attributes

Panicle weight (g)

The mean panicle weight was reduced from 3.03 g in C to 2.67 g in Ws, 1.64 g in Ht and 1.45 in Ht+Ws (Table 3). Among the genotypes, maximum panicle weight was recorded in Rasi (2.97 g) and minimum in N22 (1.74 g). Rasi recorded maximum panicle weight in all the treatments; in C (3.70 g), Ws (3.33 g), Ht (2.50 g) and Ht+Ws (2.33 g). Minimum in C and Ws was in N22 (2.07 and 1.90 g respectively) and in Ht and Ht+Ws in MTU1001 (1.17 and 1.00 g respectively).

Number of grains panicle^{-1}

The mean number of grains panicle^{-1} dropped from 119 in C to 110 in Ws (8.1% reduction over control), 106 in Ht (11.5% reduction over control) and to 98 in Ht+Ws (17.9% reduction over control). Among the genotypes, maximum grains panicle^{-1} were noted in Rasi (119) and minimum in N22 (95). The interaction between TxG was non-significant, however, in C, Ws, Ht and Ht+Ws the highest number of grains panicle^{-1} was observed in Rasi (130, 122, 116 and 107 respectively) and minimum was in N22 (99, 94, 94 and 91, respectively) (Table 3).

Filled grains panicle^{-1}

The mean number of filled grains panicle^{-1} was maximum in C (110) which reduced to 90 (Ws), 54 (Ht) and 47 (Ht+Ws) (Table 3). Maximum filled grains panicle^{-1} was noted in Rasi (98) and minimum was in MTU1001 (59). In C, Ws, Ht and Ht+Ws, the highest number of filled grains panicle^{-1} was observed in Rasi (121, 110, 86 and 75 respectively). The lowest in C was in N22 (90), in Ws and Ht+Ws in MTU1001 (74 and 20 respectively) and in Ht in both MTU1001 and Vandana (30).

Spikelet fertility (%)

The mean spikelet fertility of all the genotypes was reduced in all the treatments (Ws, Ht and Ht+Ws) when compared to control. It was 91.7% in C, 82% in Ws, 51.8% in Ht and 47.4% in Ht+Ws (Table 4). Among the tested genotypes, maximum spikelet fertility was noted in Rasi (81.9%) and N22 (81.8%) and minimum in MTU1001 (52.6%). Maximum spikelet fertility in C and Ws was in Rasi (93.3% and 89.7% respectively), in Ht and Ht+Ws in N22 (76.6% and 72.8% respectively). Minimum was in Vandana in C (91.0%) and Ht (27.6%). Under Ws and Ht+ Ws it was in MTU1001 (69.0% and 20.8% respectively).

1000 grain weight (g)

There was a reduction in 1000 grain weight under Ws, Ht and Ht+Ws condition (Table 4). The highest value was in C (19.85 g) and the lowest was in Ht+Ws (8.72 g). Among the genotypes, maximum 1000 grain weight was recorded in Rasi (17.75 g) and minimum in MTU1001 (11.63 g). In C, Ws, Ht and Ht+Ws, the highest 1000 grain weight was in Rasi (23.7, 19.0, 15.1 and 13.2 g respectively). The lowest in C was in N22 (14.73 g), in Ws in MTU1001 (11.47 g), in Ht and Ht+Ws in Vandana (7.0 and 6.10 g respectively).

Grain yield (g plant^{-1})

Imposition of Ws, Ht and Ht+ Ws led to the substantial reduction in grain yield (Fig. 1). However, the extent among the genotypes varied. The grain yield in C was 15.02 g plant^{-1} that reduced to 12.02 in Ws (19.9% reduction over control), to 8.67 g plant^{-1} in Ht (42.2% reduction over control) and to 6.07 g plant^{-1} in Ht+Ws (59.5% reduction over control). Maximum grain yield was noted in Rasi (13.65 g plant^{-1}) and minimum in Vandana (8.04 g plant^{-1}). In C, Ws, Ht and Ht+Ws

Table 1: Effect of Ht, Ws and Ht+Ws on plant height (cm) in selected rice genotypes

Genotype	Plant height (cm)									
	Vegetative stage					Reproductive stage				
	C	Ws	Ht	Ht+Ws	Mean	C	Ws	Ht	Ht+Ws	Mean
N22	73	72	82	81.2	76.9	88	86.1	94	92.3	90
Vandana	83	82	84	83.5	83.2	104	101	107	93.7	101
Rasi	75	74	76	75.6	75.2	86	84.6	88	84.5	85.9
MTU1001	77	75	81	80.3	78.3	85	82.3	89	86	85.4
Mean	77	76	80	80.1		91	88.4	94	89.1	
LSD (T)	1.90 (P<0.01)					3.49 (P<0.01)				
LSD (G)	3.83 (P<0.01)					4.43 (P<0.01)				
LSD (TxG)	2.67 (P<0.01)					4.87 (P<0.05)				

C-Control, Ws- Water stress, Ht- High temperature and Ht+Ws- High temperature and water stress

Table 2: Effect of Ht, Ws and Ht+Ws on days to 50% flowering and days to maturity in selected rice genotypes

	Days to 50% flowering				Days to maturity			
Genotype	C	Ws	Ht	Ht+Ws	C	Ws	Ht	Ht+Ws
N22	76	76	71	70	97	95	90	88
Vandana	75	75	62	60	96	93	79	76
Rasi	80	80	72	71	116	114	103	101
MTU1001	87	86	76	74	118	114	101	97
Mean	80	79	70	69	107	104	93	91

Table 3: Effect of Ht, Ws and Ht+Ws on panicle weight (g), number of grains panicle^{-1} and filled grains panicle^{-1} in selected rice genotypes

Genotype	Panicle weight (g)					Number of grains panicle^{-1}					Filled grains panicle^{-1}				
	C	Ws	Ht	Ht+Ws	Mean	C	Ws	Ht	Ht+Ws	Mean	C	Ws	Ht	Ht+Ws	Mean
N22	2.07	1.9	1.6	1.4	1.74	99	94	94	91	95	90	82	72	66	77
Vandana	3.27	2.9	1.3	1.07	2.13	126	115	108	100	112	115	94	30	26	66
Rasi	3.7	3.33	2.5	2.33	2.97	130	122	116	107	119	121	110	86	75	98
MTU1001	3.1	2.53	1.17	1	1.95	122	107	104	95	107	113	74	30	20	59
Mean	3.03	2.67	1.64	1.45		119	110	106	98		110	90	54	47	
LSD (T)	0.33 (P<0.01)					7.47 (P<0.01)					6.44 (P<0.01)				
LSD (G)	0.17 (P<0.01)					5.10 (P<0.01)					5.00 (P<0.01)				
LSD (TxG)	0.34 (P<0.01)					NS					10.0 (P<0.01)				

Table 4. Effect of Ht, Ws and Ht+Ws on spikelet fertility (%), 1000 grain weight (g) and harvest index (%) and in selected rice genotypes

Genotype	Spikelet fertility (%)					1000 grain weight (g)					Harvest index (%)				
	C	Ws	Ht	Ht+Ws	Mean	C	Ws	Ht	Ht+Ws	Mean	C	Ws	Ht	Ht+Ws	Mean
N22	90	87	77	72.8	81.8	14.7	13.9	9.6	8.57	11.7	53	49	44	42.6	47.0
Vandana	91	82	28	25.7	56.6	20.7	18.1	7.0	6.1	13.0	50	47	37	36.0	42.7
Rasi	93	90	74	70.2	81.9	23.7	19.0	15.1	13.2	17.8	50	48	44	42.2	46.0
MTU1001	92	69	29	20.8	52.6	20.3	11.5	7.8	7.0	11.6	50	44	38	35.9	42.1
Mean	92	82	52	47.4		19.9	15.6	9.9	8.72		51	47	41	39.2	
LSD (T)	6.37 (P<0.01)					1.77 (P<0.01)					7.38 (P<0.01)				
LSD (G)	3.43 (P<0.01)					1.82 (P<0.01)					NS				
LSD (TxG)	6.87 (P<0.01)					3.65 (P<0.01)					NS				

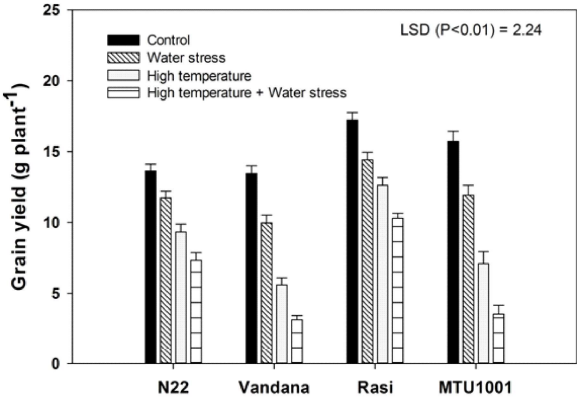

Fig 1. Effect of Ht, Ws and Ht+Ws on Grain yield (g plant^{-1}) in selected rice genotypes

maximum grain yield was noted in Rasi (17.23, 14.43, 12.63 and 10.30 g plant^{-1} respectively) and minimum in Vandana (13.47, 9.97, 5.60 and 3.13 g plant^{-1} respectively).

Harvest index (%)

There was a reduction in mean harvest index in all the genotypes under Ws, Ht and Ht+Ws. The harvest index reduced from 50.8% in C to 47.2% in Ws, to 40.6% in Ht and to 39.2% in Ht+Ws. The effect of treatment and genotypes interaction was non-significant (Table 4).

High temperature and water stress conditions had a negative impact on yield and yield attributes. Rice grain yield and yield attributes like grain size and grain weight were severely reduced under drought stress (Venuprasad *et al*., 2011). A reduction in 1000-grain weight and increase in spikelet sterility is commonly observed under drought stress (Kumar *et al*., 2014). Drought stress at vegetative growth especially at booting and flowering stage can interrupt floret initiation causing spikelet sterility and lowering grain weight and ultimately poor yields. The above findings are in agreement with our results as we also observed reduction in the yield and yield attributes among the rice genotypes. High temperature induced reduction in yield and yield attributes was proven experimentally by Poli *et al*. (2013). Vikender and Behl (2010) reported that all the stress treatments viz. high temperature, drought and interaction of high temperature and drought resulted in a decrease in grain number spike^{-1}, grain weight spike^{-1} and test weight and hence resulted in reduction in grain yield of var. UP2565 (tolerant genotype) than var. WH730 (susceptible genotype). They stated that the effects of high temperature and drought on grain yield are additive. Similarly in our experiment, the extent of reduction in yield was higher in MTU1001 and Vandana (susceptible genotypes) and lesser was noted in N22 and Rasi (tolerant genotypes). The reduction in yield and yield related parameters was higher under combined stresses than individual stresses alone.

CONCLUSION

Hence from the present experiment it can be concluded that all the yield components and yield were affected by water stress and high temperature stress and the extent of reduction was higher under combined stress. Among the genotypes, comparatively N22 and Rasi were tolerant to the stress as observed by a lesser reduction in their yield and yield components.

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