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Assessment of Day Time Anthesis Warming on Rice Cultivars under Varying Textured Sites of South-Western Punjab, India

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Abstract

Rice production is highly influenced by the prevailing weather conditions, physico-chemical properties of the soil, the yielding potential of cultivars besides, several crop management practices and inputs. To understand the performance of the tiller production of various paddy cultivars under varying soil texture sites of the south-western Punjab, four rice cultivars *viz.*, PR121 (V_1), PAU201 (V_2), PR128 (V_3) and PR129 (V_4) were grown at three different locations having soil texture from light to heavy. Sowing of nursery was completed between May 15, 2019 and May 23, 2019 however, seedlings were transplanted in the well prepared field during 05-20 June, 2019. Results of the present study clearly depicted the role of weather parameters on plant height, effective tillers, grain yield and spikelet sterility in the rice crop. High temperatures have detrimental effects on fertility of rice varieties, regardless the transplanting time. Among different rice cultivars, sterility was the lowest (17.8%) in PR121 and the highest 42.6% in PR129. Apart from the varietal differences, the lowest sterility 28.4% recorded in medium textured soil was lowered by 21.5% and 27.8% than light and high textured soils. Cultivar PR121 produced 3.9%, 7.7% and 15% higher grain yield than PR128, PAU201 and PR129, respectively. The response of anthesis period thermal stress on spikelet sterility should be considered to develop the temperature tolerant varieties for addressing the climate change issues.

Keywords

Rice, Soil Texture, Spikelet Sterility, Thermal Stress

1. Introduction

Rice, an important crop for India and world, plays a very significant role in agrarian economy of the nation. Rice production in India has been significantly increased from 20.6 million tonnes during 1950-1951 to 116.48 million tonnes during 2018-2019. Rice production is highly influenced by the prevailing weather conditions, physico-chemical properties of the soil, yielding potential of the cultivars in addition of several crop management practices and other inputs. For rice crop, optimum temperature is 25˚C - 31˚C for tiller production, 30˚C - 33˚C for anthesis and 20˚C - 29˚C for ripening [1]. Both low as well as high temperatures prevailing from panicle initiation to flowering stages of rice may cause the spikelet sterility in rice [2] [3] and [4]. Temperature below 18˚C for two or more days between panicle initiation and booting stage leads to spikelet sterility [5] likewise, temperature at 35˚C or above during flowering stage also enhances spikelet sterility [6]. Global warming is projected to be continued causing temperature to rise by 0.3˚C to 4.8˚C at the end of this century compared to baseline of 1986-2005 [7]. Any risk of the elevated temperature particularly around anthesis stage may lead the spikelet sterility through producing the higher number of the empty spikes.

Prevalence of heat stress for extended duration during reproductive phases of crop seriously deteriorate the quality of rice production [8] in similar fashion as for wheat [9] that is expected to further aggravate under changing climatic conditions [10]. Because, spikelet sterility is expected to become a serious problem under elevated air temperatures [11]. In future with advancement of global warming, the more frequent heat-induced spikelet sterility may cause the high instability of rice production [12]. Similarly, [13] also discussed that the heat-induced spikelet sterility in rice mainly occurs due to exposure of panicles to heat stress between booting and flowering stages. In fact, the environmental variables largely govern the crop growth and development besides affecting the rate of various physiological processes within plant body. For example, spikelet sterility begins when the daily maximum temperature reaches approximately at or above 34˚C - 36˚C [14] [15] and [16]. In addition, high humidity also promotes spikelet sterility [16] and [6]. Similarly, low humidity [13], wind [6], and high CO_2 concentration [6] also influence the sterility. The mechanism(s) of rice spikelet sterility caused by high temperatures includes the reduction of full development of pollen [14], faulty dehiscence of anthers [13] and [17] hence, low number of healthy pollen grains at the stigma [13]. Generally, panicles of rice plants are heat-sensitive organ hence, heat-induced spikelet sterility causes a severe decline in the fertility.

Among several environmental factors influencing the growth and yield of crops the light, temperature and moisture both in air and soil are most important. The optimum set of climatic variables for good growth of crops can be easily obtained only through altering the transplanting time for rice. Early or optimum transplanting may increase the grain yield of hybrid rice [18] and [19] but, late transplanting often leads to sub-optimal productivity of rice owing to the shortening of vegetative period [9]. Therefore, determination of optimum time of transplanting is crucial for hybrid rice due to its thermo-sensitivity nature over conventional inbreed high yielding cultivars [20] The objectives of this study are: 1) to study the effect of high day temperature on spikelet sterility, grain yield and yield attributes of rice cultivars at different soil textured sites, 2) to work out the level of thermal stresses during anthesis stage, 3) to optimize the transplanting dates for avoiding thermal stress at anthesis, and 4) to develop prediction model to assess the spikelet sterility.

2. Material and Methods

Adoptive research trials have been conducted in south-western regions of Punjab during May-October, 2019. Agro eco-situations were made on the basis of soil type. The experimental soil of different sites (**Figure 1**) was light, medium and heavy textured. The composition of the soil at each experimental site has

Figure 1. Location map of experimental sites.

been presented in **Table 1**. Four rice varieties *viz.* PR121 (V_1), PAU201 (V_2), PR128 (V_3) and PR129 (V_4) were used in which V_3 and V_4 were new varieties. The unit plot size was 500 square meter. In a well prepared field the rice seedlings (25 to 30 days old) were manually transplanted at the spacing of 20 × 15 cm using two seedlings per hill from 05th June to 20th June. For control of broadleaf weeds Algrip (Metsulfuron) 20 WP @30 g per acre in150 litres of water was applied as post-emergence at 20 - 25 days after transplanting. Based on the rainfall and field situations, irrigation was applied. Through frequent irrigation, the water shortage was avoided throughout the crop period. Nitrogen @150 kg/ha along with the phosphorus and potassium @30 kg/ha was supplied to the crop. Before the last puddling, 1/3rd dose of nitrogen and whole amount of phosphorus and potassium was applied. The remaining nitrogen was broadcasted in two splits, one at three weeks after transplanting and the second at three weeks afterwards. For the remaining cultural practices and plant protection measures, package of practices for the crops (*Kharif*) of Punjab (https://www.pau.edu/content/pf/pp _kharif.pdf) were followed.

Plants of one meter row length (5 hills each from three locations) were selected and marked for tiller counting while, the final plant height was measured from the soil surface to the tip of last leaf. The physiological maturity in the crop was determined when 95% of spikelets had turned from green to yellow considering that crop was ready to harvest. Similarly, the spikelet fertility/sterility were manually evaluated by squeezing the grains with index finger and thumb to determine whether the spikelet was filled or not. The filled grains were considered as fertile grains whereas, completely empty grains were termed as the sterile grains following [21].

The observed data were subjected to analysis of variance (ANOVA) for the randomized plot design using IBM SPSS for Windows 21.0 (IBM SPSS 21.0, Inc., Chicago, U.S.A.). All data sets were subjected to ANOVA and the differences between the treatment means were separated by the Duncan's Multiple Range Test (DMRT) post hoc test at 95% confidence interval. The treatment means difference at $p < 0.05$ were considered statistically significant. The weather data during the study period (**Figure 2**) revealed that ranging from 14˚C to 32˚C and 26˚C to 45˚C mean of minimum and maximum temperature for the crop season

Table 1. Soil composition of different experimental sites.

Parameters	Experimental sites		
	Site 1: Light texture	Site 2: Medium texture	Site 3: Heavy texture
Sand (%)	72	38	16
Silt (%)	14	44	32
Clay (%)	14	18	52
Organic carbon (%)	0.39	0.48	0.61

were 25˚C and 34˚C, respectively. Similarly, diurnal mean of the relative humidity held between 24% and 88% having 65% as seasonal average. Total rainfall 284 mm has been recorded during the crop season. The daily maximum temperature during flowering stage was averaged to work out the level of heat/thermal stress with varying intensities, describe as under:

Sr. No	Stress level	Category
1	Days > 33˚C	Moderate
2	Days > 34˚C	High
3	Days > 35˚C	Severe
4	Days > 36˚C	Extreme
5	Days > 37˚C	Extremely high

In addition, correlation coefficient was done to establish the relationship between levels of thermal stress and the spikelet sterility. Besides, the regression equations were developed to forecast the spikelet sterility of rice under varying transplanting environments.

3. Results

3.1. Variations in the Minimum and Maximum Temperature

The lowest minimum temperature held between 19.2˚C and 22.4˚C during two

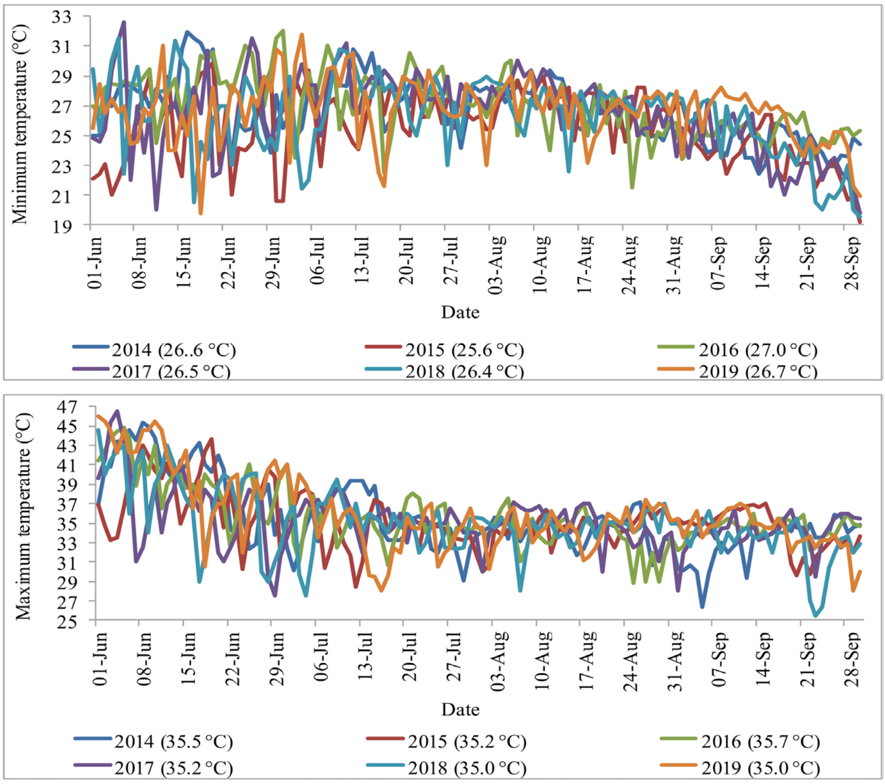

Figure 2. Minimum and maximum temperature during crop growth period.

consequtive years 2015 and 2014, respectively. While with 32.0˚C and 32.6˚C, years 2016 and 2017 recorded the highest (**Figure 2**). In different years the lowest range of the maximum temperature (25.5˚C - 44.5˚C) was recorded during the year 2018 whereas, the highest maximum temperature was 46.6˚C during 2017 followed by 46.0˚C during 2019. Ranging from 25.6˚C during 2015 to 27.0˚C during 2016, the crop season minimum temperature was 26.6˚C, 26.5˚C, 26.4˚C and 26.7˚C during the year 2014, 2017, 2018 and 2019, respectively. Besides the huge diurnal variations, the mean maximum temperature during crop season was between 35.0 (year 2018 and 2019) and 35.7˚C (year 2016), respectively. But, it was 35.2˚C (during 2015 and 2017) and 35.5˚C during 2014 (**Figure 2**).

3.2. Grain Yield

Among cultivars, significant differences were observed in grain yield at different soil textured sites. Grain yield ranged from 57.69 to 69.7 q/ha in light, 62 to 73 q/ha in medium and 62 to 73.4 q/ha in heavy textured soil. Cultivar PR121 significantly produced the highest yield on medium to heavy soils, being at par with PR128 on medium textured soil. Average grain yield across the soil textured sites was remarkably higher in PR121 and showed superiority of 3.9%, 7.7% and 15% over PR128, PAU201 and PR129, respectively. Regarding cultivars better translocation and partitioning of assimilates to grain may be the cause of higher yield (**Table 2**).

3.3. Yield Attributes

Various yield attributing characters were significant effects of different soil texture sites, cultivars on panicle length (**Table 2**). The panicle length (cm) was significantly decreased in light texture soil whereas, the highest was observed in medium texture soils. Among varieties, the variety PR129 produced lengthily panicles being identical with PR128 whereas, shorter panicles were recorded in

Table 2. Yield and yield attributes of rice cultivars in different soil textures.

Parameter	Location-I (Light texture soil)				Location-II (Medium texture soil)				Location-III (Heavy texture soil)			
	PR128	**PAU201**	**PR129**	**PR121**	**PR128**	**PAU201**	**PR129**	**PR121**	**PR128**	**PAU201**	**PR129**	**PR121**
Panicle length (cm)	22.9b	24.6c	25.0c	20.8a	27.3b	26.3b	26.8b	21.6a	25.1c	23.5b	25.7c	20.6a
Grains/panicle	74.3a	102.0c	83.5b	75.4a	102.0c	98.1b	87.7a	86.9a	88.0b	63.55a	67.1a	81.8b
Spikelets/panicle	134.1b	147.2c	147.3c	93.5a	149.1c	138.2b	138.4b	104.1a	143.9d	107.9b	128.5c	99.2a
Sterility (%)	44.6c	30.6b	43.4c	19.3a	31.6c	28.9b	36.6d	16.5a	38.8b	41.1b	47.7c	17.5a
1000-grain weight (g)	28.7bc	24.4a	29.4c	27.2b	30.6a	30.3a	31.1b	32.0b	30.9a	35. 6c	33.1b	32.2b
Effective tillers (no./hill)	9.8a	9.0a	8.6a	13.8b	10.8b	9.4a	11.2b	14.2c	10.2ab	9.6a	9.4a	12.8b
Plant height (cm)	110.4b	106.0a	120.8c	104.6a	125.6c	114.4b	116.0b	103.6a	127.2b	115.8a	128.8b	111.0a
Grain yield (q ha^{-1})	68.0b	69.2b	57.6a	67.2b	72.0b	63.0a	62.0a	73.0b	65.4a	65.0a	62.0a	73.4b

Mean values (for different variables) within a column with different alphabets are significantly different by Duncan's Multiple Range Test at $p < 0.05$.

variety PR121. This may be due to poor health status of light texture soil along with other soil physical conditions. Among varieties, lengthily panicles may be due to better genetic expression.

Large number of panicle size was observed among the cultivars and least was recorded at different soil texture sites. All cultivars had intermediate to heavy panicle size ranging from 98 to 142 spikelets per panicle. Heavy texture soil produced significantly less spikelets/panicle (119) in comparison to medium texture (132) and low textured soil (130). The new cultivars PR128 and PR129 consistently produced panicles of larger size than remaining variety. Medium textured soil exhibited more number of grains/panicle (93) followed by light (83) and heavy (75) textured soil. Among cultivars PR128 and PAU201 were more efficient in producing more grains/panicle.

Medium texture soil was relatively superior for producing more number of effective tillers/hill (10.9) closely followed by heavy texture (10.7) and light texture (9.6) soil. Among cultivar PR121 produced maximum effective tillers (11.7/hill) whereas, PR128 and PR129 were identical (10.3/hill) and least (9.3/hill) have been recorded in PAU201. Similarly, plant height varied among the rice cultivars at different textured sits. The average plant height at maturity ranged from 106.4 cm (in PR121) to 121.8 cm (in PR129). Heavy textured soils recorded remarkably taller plants (120.7 cm) in comparison to light textured soil (110.4 cm).

On average, 1000 grain weight remarkably decreased on light textured soil, whereas verities didn't show sufficient difference. It was observed that variety PR128 and PR129 being identical while, test weight was significantly higher in light textured soil, in medium textured soil. Variety PR129 and PR121 has been identical for higher test weight while, variety PAU201 had significant lead on heavy textured soil.

3.4. Spikelet Sterility

In future climates, greater heat tolerant capacity around anthesis will be required in rice. There was significant variation in spikelet sterility in rice varieties. All cultivars had shown response to higher temperature at anthesis resulting 17% - 42% spikelet sterility. Variety PR121 significantly showed high resistance to temperature. Whereas new cultivars PR129 and PR128 were more susceptible to temperature showing 42% to 37% spikelet sterility, respectively. Medium textured soil produced 27% spikelet sterility being minimum among the sites.

3.5. Level of Thermal Stresses during Rice Flowering

The rice crop experienced varying level of sterility under different trans-planting environments. The early transplanting (June 05) recorded maximum duration of 11.2, 8.7 and 4.0 days, respectively under moderate (days > 33˚C), high (days > 34˚C) and extreme (days > 35˚C) level of thermal stresses. The rice transplanted on June 10 faced minimum duration of 8.8 and 6.2 days under moderate and high thermal stress levels, respectively. But, as transplanting was delayed up to June 15 and June 20, these moderate and high stresses again increased by 0.7 days in each from June 10 transplanting, respectively. The extreme stress level was found to be decreased with each delay in rice transplanting. Similarly, level of extremely high stress (days > 36˚C) was maximum (2.2 days) under June 10, followed by 2.0 days in June 15, 1.2 days in June 05 and 1.0 days in June 20 transplanting (**Figure 3**). All the thermal levels followed second order polynomial trends, except the severe stress level that followed the linear trend. The coefficient of determination between $R^2 = 0.86$ and 0.99 showed a high level of significance in the trends of stress levels. Despite from the varietal differences, lowest sterility in medium textured soils (28.4%) was lowered by 21.5% in light and 27.8% in high textured soil. These results are evident for the adequacy of the medium texture soils for attainment of higher level of fertility in rice, in comparison of the light and the heavy textured soils. Among different rice cultivars, sterility was lowest (17.8%) in PR121 and highest (42.6%) in PR129. The critical evaluation of **Figure 3** clearly depicted that cultivar PR 121 produced lower sterility by 2.39, 2.16 and 1.89 times than in PR129, PR128 and PAU201, respectively.

Under different transplanting dates, the duration of the moderate thermal stress was 11 - 12 days in June 05, 9 - 12 days in June 10, 6 - 9 days in June 15 and 1 - 5 days in June 20 transplanting. The highest stress period existed for 9 - 12 days, 6 - 9 days and 3 - 4 days under high, severe and extreme category. Notably during 2014 and 2019, extremely high stress (day > 37˚C) has been also appeared for a single day, both years (**Table 3**).

3.6. Correlation Coefficient between Rice Sterility and Thermal Stress

The correlation coefficient between rice sterility and level of thermal stress days (**Table 4**) revealed that the spikelet sterility in both the early (June 05) and late (June 20) transplanted rice was negatively influenced by the level of thermal

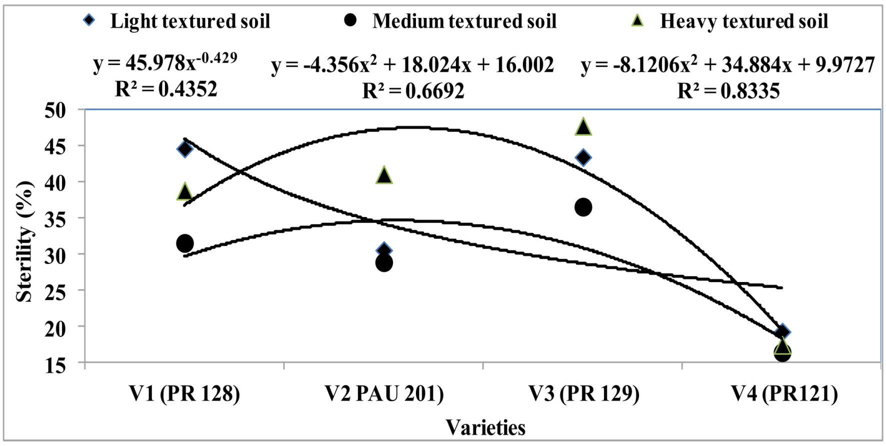

Figure 3. Sterility percentage in rice cultivars at different soil textured sites.

Table 3. Patterns of thermal stress levels during flowering of rice at different transplanting dates from 2014 to 2019.

	Days > 33˚C	Days > 34˚C	Days > 35˚C	Days > 36˚C	Days > 37˚C	Total
Transplanting: June 05, Flowering: Aug 12 to Aug 24						
2014	11	9	5	1	0	26
2015	12	10	2	0	0	24
2016	12	10	4	1	0	27
2017	11	9	7	4	0	31
2018	11	7	3	0	0	21
2019	10	7	3	1	0	21
Mean	**11.2**	**8.7**	**4.0**	**1.2**	**0.0**	**25**
Transplanting: June 10, Flowering: Aug 22 to Sep 02						
2014	7	5	4	2	1	19
2015	12	12	7	3	0	34
2016	5	0	0	0	0	5
2017	6	2	0	0	0	8
2018	11	8	3	3	0	25
2019	12	10	7	5	1	35
Mean	**8.8**	**6.2**	**3.5**	**2.2**	**0.3**	**21**
Transplanting: June 15, Flowering: Sep 1 to Sep 12						
2014	2	0	0	0	0	2
2015	12	12	9	5	0	38
2016	11	7	2	0	0	20
2017	9	5	1	1	0	16
2018	9	4	1	1	0	15
2019	12	10	6	5	0	33
Mean	**9.2**	**6.3**	**3.2**	**2.0**	**0.0**	**21**
Transplanting: June 20, Flowering: Sep 11 to Sep 22						
2014	11	5	2	0	0	18
2015	7	7	6	4	0	24
2016	10	9	6	0	0	25
2017	11	6	2	1	0	20
2018	9	3	1	0	0	13
2019	9	7	2	1	0	19
Mean	**9.5**	**6.2**	**3.2**	**1.0**	**0.0**	**20**

Table 4. Correlation coefficient between rice sterility and level of thermal stress days.

Transplanting time	Days > 33˚C	Days > 34˚C	Days > 35˚C	Days > 36˚C	Days > 37˚C
05 June	0.45	0.56	0.71	0.72	
10 June	0.91	0.92	0.91	0.96	0.33
15 June	0.36	0.53	0.69	0.86	
20 June	0.22	0.25	0.19	0.49	

stresses (June 05: r = −0.45 to −0.71 and June 20: r = −0.19 to −0.72) though, sterility in the late transplanting was increased with the occurrence of the thermal stress towards extreme category. Whereas, the sterility in the rice spikelet was simultaneously increased with the varying intensities of thermal stresses during crop flowering. Because, rice transplanting between June 10 and June 15 may experience extreme temperature episodes during flowering stage resulting more spikelet sterility. Therefore, shifting of transplanting before or after these dates may be an option to save the crop from thermal stresses.

3.7. Development of Sterility Prediction Model

The heat stress induced spikelet sterility of rice under different transplanting dates may be successfully predicted using the statistical model based on the thermal stress days. Early transplanting rice sterility could be fairly predicted by using severe thermal stress (Days > 35˚C) based model ($Y = -0.9375X + 41.75$, $R^2 = 0.50$). Similarly under optimum (June 10) transplanting time, all the stress based model may be used for sterility estimation whereas, for moderate stress based model ($Y = 0.7279X + 31.57$, $R^2 = 0.96$) was the best. Model, $Y = 0.8571X + 36.29$, $R^2 = 0.73$ based on extreme stress and $Y = -1.1304X + 48.74$, $R^2 = 0.52$ based on moderate stress have been appeared as the best model for delayed and late transplanted rice sterility (**Table 5**).

4. Discussion

Rice is extremely sensitive to heat stress. Therefore, high temperatures adversely affect the rice production [22]. In future the global mean temperature is expected to increase by >1.5˚C by the end of the 21st century. It is estimated that rising temperatures may reduce the production of rice by 41% at the end of the 21st century. During 2071-2100, annual maximum temperature of Ludhiana, Punjab may be higher by 5.8˚C, 5.4˚C and 3.1˚C in the A1B, A2 and B2 scenario than the baseline temperature (29.8˚C) whereas, winter rainfall could be deficit by 78% and 30% under the A2 and B2 scenarios, respectively [23].

Heat stress is an increase in temperature above a threshold level for a certain period that causes irreversible damage to the growth and development of plants [24]. Under future scenarios of projected warming, above critical threshold (>33˚C) high temperature extremes at flowering stage will be more frequent

Table 5. Forewarning model for sterility in rice caused by level of thermal stress.

	05-Jun		10-Jun		15-Jun		20-Jun	
	Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
Days > 33˚C	$Y = -1.4118X + 53.77$	0.20	$Y = 0.7279X + 31.57$	0.96	$Y = 0.2259X + 35.93$	0.13	$Y = -1.1304X + 48.74$	0.52
Days > 34˚C	$Y = -0.9643X + 46.36$	0.31	$Y = 0.487X + 35.0$	0.92	$Y = 0.2893X + 36.17$	0.28	$Y = -0.288X + 39.78$	0.06
Days > 35˚C	$Y = -0.9375X + 41.75$	0.50	$Y = 0.6869X + 35.56$	0.83	$Y = 0.4615X + 36.54$	0.48	$Y = -0.2013X + 38.64$	0.04
Days > 36˚C	$Y = -0.8308X + 38.97$	0.27	$Y = 1.1681X + 35.47$	0.92	$Y = 0.8571X + 36.29$	0.73	$Y = 0.75X + 37.25$	0.24

[25] [26] and [27] across different major rice growing regions. These warming seasons are likely to negatively affect the growth, development and yield of rice crops besides some physiological aberrations. To overcome such heat stress, rice plants itself possess through different tolerance mechanisms such as transpiration cooling [28]. Increasing the spikelets per panicle is an effective approach to improve rice yield [29] and [30]. Because, rice cultivars with larger panicle often show larger sink size thus, have higher yield potential than conventional cultivars [31] and [32]. In this context, [33] reported a negative correlation between the number of spikelets per panicle and the filled-grain percentage.

Average attainable yield of these rice cultivars in Punjab is 7 - 7.5 t/ha (Package of practices for the crops of Punjab, *Kharif* 2020, https://www.pau.edu/content/pf/pp_kharif.pdf). The accumulation of pre-floral photosynthate determines reproductive sink capacity [34] while, ratio of spikelet number to tiller dry weight after spikelet differentiation was well correlated with the rice yield [35]. Considerable variation in grain yield was observed among cultivars in the study, suggesting that it is possible to further improve the attainable yield of rice. The spikelet sterility data (**Table 2**) revealed that in cultivar PR 121 the spikelet sterility was only 17%, being minimum among cultivars thus, showed lower thermal stress at anthesis. Such type of genotypes may be exploited for future breeding program to develop high day temperature tolerant varieties. Similarly, [21] and [36] also reported that the levels of thermal stresses reduce the grain yield losses mainly through the spikelet sterility and reduced grain weight.

The soil texture or structure can immensely affect the crop production by altering the root growth system because growth of the roots in a same cultivar may considerably vary with soil texture [37]. The panicle length was affected by different soil texture sites and was significantly decreased in the light soil. It may be due to less fertility status of light textured soil than other soil physical conditions. Among cultivars shorter panicle was recorded in PR121. All the cultivars had intermediate to heavy panicle size ranging from 98 to 142 spikelets per panicle. The cultivars PR128 and PR129 consistently produced panicles of large size than PR121 that would be a prime factor for high yield in PR128 and PR129. Likewise, [38] has already explained that the rice cultivars having heavy panicle size attains high yield potential that may be an appropriate measure for developing new high-yielding varieties. Again, cultivar PR121 produced maximum effective tillers (11.7/hill) whereas PR128 and PR129, were identical (10.3/hill). Similarly, [39] also reported that cultivars with larger panicle produced fewer tillers than the cultivars with smaller panicles. When comparing the results of four cultivars at different textured soils, it was determined that cultivars presented high genetic variability in yield. Cultivar P 121 showed superiority over other cultivars across the soil textures. The better translocation and partitioning of assimilates towards grains may be the cause of higher yield.

Different cultivars showed differential responses against higher temperature.

PR121 showed relatively high resistance to temperature than other cultivars. The cultivar PR129 and PR128 was more susceptible to temperature recorded 42% to 37% spikelet sterility, respectively. One hour at a spikelet tissue temperature of ≥33.7˚C was sufficient to cause sterility and this coincided with anthesis stage [13]. At anthesis stage, even a shorter episode (>35˚C for ≥1 h) of heat stress badly affects the spikelets [40] and [41] while, >38˚C for ≥1 temperatures after anthesis have minimal impact on it [42] and [43].

Although heat stress primarily affects anther dehiscence [15] [44] and [21], it is possible that in susceptible cultivar such as PR129, PR128 and PAU201 a number of other processes like, pollen swelling, another pore size is affected before fertilization [45], and pollen stickmens may also affect the growth [46]. The magnitude of sterility in a number of genotypes is related to the low content of non structural carbohydrate in panicle tissues at the meiotic stage [47]. The panicle length was affected by soil texture sites and was significantly decreased in the light textured soil. Among cultivars shorter panicle in PR121 may be due inherent genetic the cultivar characters. The lowest plant height was in PR121 (106.4 cm) and maximum in PR129 (121.8 cm). Cultivars with large panicle also have greater plant height [48]. Heavy textured soil recorded remarkably taller plants mainly because of better soil fertility status than low textured soils.

5. Conclusion

High temperature has a positive effect on spikelet sterility rate of rice varieties. Though, impacts of high temperature on grain weights of different rice varieties are diversified. High temperatures have detrimental effects for rice fertility. Under different transplanting dates, stress period was 9 - 12 days, 6 - 9 days and 3 - 4 days under high, severe and extreme category. Extremely high stress (day > 37˚C) was also recorded for a single day, during 2014 and 2019. Among different rice cultivars, sterility was the lowest (17.8%) in PR121 and the highest (42.6%) in PR129. The higher grain yield in PR121 showed superiority of 3.9%, 7.7% and 15% over PR128, PAU201 and PR129, respectively. Besides with minimum spikelet sterility of 17%, cultivar PR121 showed lower thermal stress at anthesis and described that such type of genotypes may be encouraged to develop the temperature tolerant varieties. The developed regression model may be useful for better understanding and advance estimation of the occurrence of the thermal stress in rice crop under various soil textures and planting environments.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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