Journal of Stress Physiology & Biochemistry, Vol. 16, No. 2, 2020, pp. 57-66 ISSN 1997-0838
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ORIGINAL ARTICLE

OPEN ACCESS

Effects of Low temperature at various growth stages and yield of different rice (*Oryza sativa* L.) genotypes

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Received January 26, 2020

The experiment was conducted with two IRRI lines and two BRRI varieties at the research field of Plant Physiology Division of Bangladesh Rice Research Institute (BRRI), Gazipur during October 2010 to September 2011 in Boro season to study the low temperature as cold tolerance effect on rice at vegetative and reproductive stages. All the genotypes (IR77496-31-2-1-3-1, IR62266-42-6-2, BRRI dhan28 and BRRI dhan36) of transplanting date 30 November, 15 December and 30 December showed higher yield except 15 November transplanted rice. The 15-November transplanted rice appeared with a significant cold in the reproductive stage. Moreover, BRRI dhan28 was not found to observe as tolerant to low temperature in reproductive stage, and produced the lowest yield 0.71 t/ha and highest (39.47%) sterility. BRRI dhan36 resulted yield 2.18 t/ha and exerted its ability to withstand the jolt of cold to some extent at the reproductive phase and IR62266-42-6-2 pronounced significantly better performance compared to BRRI dhan36. The IR77496-31-2-1-3-1 genotype exhibited the highest yield (4.27 t/ha) and marked as tolerant to cold temperature. All the genotypes performed the highest sterility percentages on 15-November transplanted rice except the genotype of IR77496-31-2-1-3-1 with lower sterility. Vegetative and reproductive stages were encountered at cold temperature in the month of January, 2011. The panicle initiation stage was fallen with (13.1 ºC) low temperature and maximum temperature (25.6 ºC) in 2nd week of February, 2011 during grain formation stage. Number of grains was naturally degenerated in growth stages where reduction division stage or pollen formation was happened in booting stage. Earliest transplanted date (15 November) revealed the shortest plant height and panicle length at low temperature. Duration of PI, growth and maturity stages were decreased with the advancement of transplanting dates of 30 November, 15 December and 30 December.

Key words: Boro season, Cold tolerance, Genotype, Low temperature, Oryza sativa L., Yield

Rice is a major cereal crop in Bangladesh, and it is also the most important staple food for a larger part of Asia of the world's human population (Ghadirnezhad and Fallah, 2014). Rice is grown in different environments with water sources and temperate conditions (IRRI, 2013). Yield variation of rice often has been attributed to low temperature in the reproductive phase during Boro season in Bangladesh (Haque and Islam, 1990; Haque *et al.*, 1992; Islam and Morison, 1992). Low temperatures caused yield losses resulting incomplete pollen formation and subsequent floret sterility, and yield losses were found to occur when the temperature falls on 18 °C and lower (Singh *et al.,* 2005). Cold stress is a common problem in rice cultivation and affects global production as a crucial factor (Zhou *et al.,* 2012). Yield losses were up to 80% in certain area with years of lower temperature (Shimono *et al.,* 2007).

Cold temperature regime causes cold damage which depends on variety and growth stages of rice plant. Cold injury were associated with low seed germination, slow growth of seedlings and leaf discoloration, stunted vegetative growth and tillering, incomplete panicle exertion, prolonged flowering period with irregular heading, degeneration of spikelets, irregular maturity, sterility and formation of abnormal grains (Kaneda and Beachell 1974; Shibata 1979; Hamdani 1979).

Farrell *et al.* (2001 and 2006) reported that rice was susceptible to abundant Low temperature (LT)-induced damage during the young microspore stage, and 12 h of exposure to LT can cause spikelet sterility. The young microspore stage was the most susceptible to cold injury in rice plants (Satake and Hayase 1970) and this stage was found to remain approximately 10 to 12 days prior to heading (Satake and Hayase 1970; Heenan 1984). Spikelet sterility might be resulted from pollen abortion due to cold during microsporogenesis, while pollen grains were formed in booting stage (Mackill *et al.* 1996). Low temperatures in grain-filling caused immature, green, abnormal and dead grains, and contents of crude protein and amylase in endosperm of rice grains (Huang & Lur 2000; Ahmad *et al.* 2008).

Low temperature is a common problem in rice cultivation in temperate zones and high-elevation environments in tropical and subtropical areas, and in irrigated areas with use of cold water (Ye *et al.*, 2009). Prevailing of low temperature was found from October to early March. The temperature often reaches below 20 °C. Low temperature may affect not only the Boro rice plant at the reproductive stage of rice but in the other stages also. Parallel to the low temperature, high temperature plays an important role in alleviating the effect of low temperature (Kabir *et al.,* 2015). Particularly, early-established short duration variety cannot escape the low temperature of its important growth stages, while the high temperature appears to stay at several degrees low in the same time (Kabir *et al.,* 2015). High grain sterility (40 - 90%) due to unusual fall of temperature in March resulted crop failure in several regions of Boro field in 1990, Bangladesh (Haque and Islam, 1990; Haque *et al.,* 1992). Low temperature-induced sterility was normally attributed to low night temperatures, while high day temperatures appear to reduce the effects of low night temperatures (Yoshida, 1981b).

Farmers grow crops without considering the growth duration and other physiological characteristics of the varieties, and consequently the crops suffer from low temperature or cold damage in Boro season. The irregularities in weather parameters are now considered as the result of global warming. Nevertheless, we need a variety with shorter growth duration independent of low temperature. A few lines have been screened as tolerant to low temperature among the huge number of breeding lines (Nahar *et al.,* 2009). The present study has been designed to find out the critical temperature to privilege growth and development of the most effective cultivar that tolerate low temperature stress in reproductive stage.

MATERIALS AND METHODS

Field experiments - The experiments were carried out at the research farm in Plant Physiology Division of Bangladesh Rice Research Institute (BRRI), Gazipur during October 2010 to September 2011. It was located at the Madhupur tract (24° 54' latitude and 90° 30' longitude) at an elevation of 8.4 m above the sea level. Two BRRI rice (*Oryza sativa* L.) varieties, such as BRRI dhan28 (Susceptible to low temperature) and BRRI dhan36 (Tolerant at the vegetative stage), and two IRRI breeding lines viz., IR77496-31-2-1-3-1 (low temperature tolerant) and IR62266-42-6-were used**.** The experiment was laid out in a 3-replicated split-plot design. Variety in the main plot and plantation date in the sub-plot 2 (low temperature tolerant) were applied in this study. The field was fertilized as per recommendation of Bangladesh Rice Research Institute, Gazipur (BRRI 2007).

Soil and climate. The soil of BRRI farm belongs to Terrace soil type with silt clay in surface and silt clay loam in sub surface region representing the area of agro ecological zone of Madhupure tract (AEZ-28). It is situated in the subtropical climate zone characterized with heavy rainfall during the months from May to September and low rainfall in the rest of the year. Meteorological data on temperature from October 2010 to March 2011 were obtained from the meteorological station of BRRI as presented in figure 1.

Sowing of seeds. Seeds of two BRRI varieties and two IRRI lines were collected from Bangladesh Rice Research Institute (BRRI), Gazipur. Seeds were sown in October 15, 30 and November 15, 30 of 2010. October 15 was regarded as first sowing time whereas November 30 was last sowing time. Thirty-day-old seedlings were uprooted from seed bed and three seedlings per hill were transplanted in the field. The individual plot size was 4.0 m x 4.0 m (16 m^2). Hill to hill and row to row distances were 20 cm and 20 cm, respectively. November 15 was followed as first transplanting date, while December 30 was last transplanting time.

Data collection and Statistical analysis. Plant height, number of panicles per plant, days to 50% flowering, number of spikelet per panicle, 1000-grain weight and grain yield were recorded. All the recorded data on different parameters were analysed statistically. The findings were analysed by partitioning the total variance with MSTAT-C computer programme. The treatment means were compared using Least Significance Difference (LSD) at 5% level of significance.

RESULTS

Yield and yield components of genotypes in low temperature.

Most of the yield and yield component effects were found significant among interaction effects (Table 1). Parameters like panicle no./m^2, grain no./m^2, 1000-grain weight and yield were quite acceptable except the sterility percentage. The first seeding date of the experiment was done intentionally, while the low temperature at its reproductive stage as to encounter the crop. The similar stresses at the succeeding seeding dates were optional. The objective of the study is to understand the behaviour of the genotypes in low temperature as cold impact in this study.

Effect of low temperature as cold on yield.

The lowest yield 0.71 t/ha, 2.18 t/ha, 2.81 t/ha and 4.27 t/ha were found with BRRI dhan28, BRRI dhan36, IR62266-42-6-2 and IR77496-31-2-1-3-1, respectively in 15 November transplanting date, while all the genotypes of transplanting dates 30 November, 15 December and 30 December produced higher yield except 15 November (Table 1). It was evident that the 15-November transplanted rice appeared with a significant cold in the reproductive stage. This stage was fallen with low temperature, while the lowest minimum temperature (9.4 and 8.95 ºC) was obtained in 2nd and 3rd week of January, 2011, respectively and maximum 20.95 ºC and 23.28 ºC was recorded in two weeks (Fig. 1). The popular BRRI dhan28 was not found to show as cold tolerant in this experiment. This variety could barely produce yield (0.71 t/ha) with low temperature in reproductive stage, while BRRI dhan36 showed similar growth duration than that of BRRI dhan28 as tolerant to cold at the vegetative stage. BRRI dhan36 signified ability to withstand the jolt of cold to some extent at the reproductive phase of the crop and resulted yield 2.18 t/ ha. IR62266-42-6-2 pronounced significantly better performance compared to BRRI dhan36. However, this genotype produced 2.81 t/ha as a response of good harvest whereas the popular variety BRRI dhan28 failed to produce as good yield. Higher than four ton per hectare was attained in the best genotype of IR77496-31-2-1-3-1 and exhibited tolerant to cold temperature. Significant difference was not found among the genotypes in case of 1000-grain weight and panicle number per square meter. All the genotypes performed the highest sterility percentages on 15-November transplanted rice except the IR77496-31-2-1-3-1 genotype with lower (15%) sterility.

Yield components in reproductive stage.

The variation of yield was achieved due to grain number per square meter (Table 2). The genotypes IR77496-31-2-1-3-1 had the highest number of grain/M^2 but not significantly different to others, whilst it exhibited significant difference in case of yield. The highest number of grain and lowest percentage of sterility indicated the ability of a genotype to tolerate the low temperature at the agronomic panicle initiation stage (API) and booting stage. The stages of agronomic panicle initiation, booting and anthesis were the most sensitive stages to cold to cause grain sterility. The crop resulted its cold shock at the two critical stages like agronomic panicle initiation stage and booting stage in this study. The agronomic panicle initiation was the grain formation stage. However, initial numbers of formed grain were naturally degenerated in growth stages of BRRI dhan28 at 15 November transplanted rice. But the degeneration may be quite high to reduce the grain number/M^2. Consequently reduction division stage or pollen formation was happened during booting stage.

Yield and sterility percentage in cold temperature.

IR62266-42-6-2 resulted comparatively less number of grain/M2 (16130.56), and observed higher sterility percentage (21.71%) in cold temperature. Lowest temperature 9.4 ºC and 8.95 ºC was obtained in 2nd and 3rd week of January, 2011, respectively and maximum temperature (20.95 ºC and 23.28 ºC) was noted in two successive weeks. Average minimum temperature 12.41ºC was recorded at 3rd week of December, 2010 and 13.1 ºC in February 2nd week, 2011, and highest 25.64 ºC and 28.19 ºC was observed in two weeks (Fig. 1). Vegetative and reproductive stages were encountered with low temperature in the month of January, 2011, while panicle initiation and booting stages were also appeared at minimum and maximum temperature in 2nd week of February on 15-November transplanted rice. The genotype (IR62266-42-6-2) was found to have lower tolerance to cold both at the agronomic panicle initiation stage as well as booting stage. BRRI dhan36 marked more or less similar reaction to the cold. However, the genotype resulted in significantly lower grain yield than that of IR62266-42-6-2 with higher grain sterility (31.53%). Conversely, BRRI dhan28 was found as less tolerance to cold both at the agronomic panicle initiation and booting stage with the lowest grain number/M2 (13427.78) and highest percentage of sterility (39.47%) at 15 November transplanting date in the lowest temperature (Table 2 & Fig. 1).

Late transplanting date with higher temperature and yield.

Yield and yield contributing attributes were found to improve with the advancement of day condition as the temperature increasing in the following late established planting dates at 30 November, 15 December and 30 December. Variation of maximum and minimum temperature was observed in the month of February and March, 2011 and reduced yield variation among the genotypes in late transplanted rice. The improvements were noticed for BRRI dhan28 and more or less similar for BRRI dhan36 and IR62266-42-6-2, but little indifferent for IR77496-31-2-1-3-1 genotype as shown in Table 2 & Fig. 1.

Plant height and Days to maturity at low temperature

Earliest transplanting date (15-November) showed the shortest plant height and panicle length (Table 3). Little difference was found between these two parameters at the other transplanting dates. It was indicated that cold temperature had adverse impact both on plant height and panicle length. The Panicle Initiation (PI) date, flowering date and growth duration followed the similar pattern in case of low temperature (Table 3). Duration of PI and growth stages were decreased with the advancement of transplanting dates of 30 November, 15 December and 30 December in increased temperature. Total days to 50% flowering and maturity of 15 November transplanting were found to have more days whereas gradually decreasing with total days of 30 November, 15 December and 30 December transplanting time (Table 3). BRRI dhan28 and BRRI dhan36 resulted similarity in growth duration, so they had their PI on the same date (Table 3) and they should have also the same flowering date. In fact that did not happen, when BRRI dhan36 wasrequired 117 day to PI and flowering at 145 days that probably avoiding the difficult cold shock at agronomic panicle initiation stage. Panicle initiation (PI) stage was obviously recorded between 25 - 30 days prior to 50% flowering. As a result BRRI dhan36 experienced better yield compared to BRRI dhan28.

Table 1: ANOVA and the Probability of the test of significance of different source of variation with respect to yield and yield components.

Source of variation	DF			Probability of significance				
		Plant height (cm)	Panicle length (cm)	Panicle/ m^2	Grains/ m^2	% Sterility	1000 Grain weight	Yield (t/ha)
G	3	0.0000	0.0000	0.0000	0.0007	0.0000	0.0000	0.0000
S	3	0.0000	0.0104	0.02555	-	0.3529	0.0000	0.0000
GXS	9	0.0039	-	0.0000	0.0118	0.0006	0.0256	0.000
Error	30							
Total	41							

Table 2: Yield and yield components of four genotypes at different seeding times

Treatments			**Panicle/ m^2**	**Grains/ m^2**	**% Sterility**	**1000 Grain weight**	**Yield (t/ha)**
	Seeding date (S)	Genotype (G)					
S1G1	15-Oct	IR77496-31-2-1-3-1	521.00	25080.56	15.29	20.44	4.27
S1G2		IR62266-42-6-2	531.67	16130.56	21.71	20.39	2.81
S1G3		BRRI dhan28	492.00	13427.78	39.47	21.75	0.71
S1G4		BRRI dhan36	474.33	18944.44	31.53	22.40	2.18
S2G1	30-Oct	IR77496-31-2-1-3-1	487.00	28150.00	11.90	24.12	6.07
S2G2		IR62266-42-6-2	428.67	28647.22	13.29	19.94	4.34
S2G3		BRRI dhan28	403.00	26697.22	7.68	21.83	4.24
S2G4		BRRI dhan36	593.00	20066.66	25.46	21.65	4.37
S3G1	15-Nov	IR77496-31-2-1-3-1	497.00	20480.56	22.36	24.23	4.41
S3G2		IR62266-42-6-2	367.67	23805.55	10.74	23.17	5.09
S3G3		BRRI dhan28	350.00	28927.78	8.57	21.64	4.87
S3G4		BRRI dhan36	438.67	28008.33	11.83	24.54	6.00
S4G1	30-Nov	IR77496-31-2-1-3-1	461.33	22644.44	16.09	23.59	3.78
S4G2		IR62266-42-6-2	367.67	26041.67	15.13	23.12	5.05
S4G3		BRRI dhan28	328.67	24386.11	16.91	20.32	4.27
S4G4		BRRI dhan36	391.00	26791.67	10.46	25.04	4.82
CV%			17.23	18.84	37.73	7.18	7.60
LSD (5%)			**155.80**	**8225.00**	**12.13**	**2.95**	**0.59**

Table 3: Plant height, panicle length, days to 50% flowering and growth duration of four varieties

Treatments			Plant height (cm)	Panicle length (cm)	Days to 50% flowering	Growth duration
	Seeding date (S)	Genotype (G)				
S1G1	15-Oct	IR77496-31-2-1-3-1	76.97	18.77	149.67	175.67
S1G2		IR62266-42-6-2	79.37	19.68	148.33	176.33
S1G3		BRRI dhan28	72.63	16.37	137.67	171.67
S1G4		BRRI dhan36	71.47	18.31	145.33	172.00
S2G1	30-Oct	IR77496-31-2-1-3-1	76.70	20.22	144.67	170.67
S2G2		IR62266-42-6-2	89.33	21.97	138.00	166.33
S2G3		BRRI dhan28	90.27	20.33	145.67	169.67
S2G4		BRRI dhan36	82.57	19.04	148.67	173.33
S3G1	15-Nov	IR77496-31-2-1-3-1	94.40	23.13	144.67	169.67
S3G2		IR62266-42-6-2	92.30	22.54	137.00	163.00
S3G3		BRRI dhan28	100.77	21.78	133.67	157.00
S3G4		BRRI dhan36	80.30	20.21	137.67	169.33
S4V1	30-Nov	IR77496-31-2-1-3-1	98.98	23.63	139.33	164.33
S4G2		IR62266-42-6-2	97.63	23.63	132.00	157.00
S4G3		BRRI dhan28	97.10	22.66	130.33	153.33
S4G4		BRRI dhan36	81.23	21.64	128.33	151.67
CV%			5.79	7.83	-	-
LSD (5%)			**9.17**	**3.07**	**2.57**	**2.05**

DISCUSSION

Performance of genotype with yield in low temperature

Nahar *et al.* (2009) reported that the genotype IR62266-42-6-2 showed tolerant at the vegetative and reproductive stage and observed significantly better performance compared to of BRRI dhan36. They also reported that the line IR77496-31-2-1-3-1 revealed tolerant genotype to low temperature both at the vegetative and reproductive phase.

Evaluation of low temperature as cold on yield

Ye *et al.* (2009) reported that low temperature had the potentiality to affect growth and development of rice plants from germination to grain filling stage. Similar findings were supported by Ye *et al.* (2009). They also observed that low temperature caused a significant decline in spikelet fertility at booting and flowering stages. Yoshida (1981a) reported that sensitivity to cold temperature (10 - 13 °C) for cold damage in the early stages of development (germination and vegetative), while higher threshold temperature (18 - 20 °C) marked less sensitive than the reproductive stage. Similar observations were also supported by (Kabir *et al.,* 2015). Cruz *et al.* (2006) studied that low temperature (17 °C) resulted in non-uniform seedling growth and weak seedlings, and affected final grain yield. Similar observations were reported by Yuan *et al.* (1999).

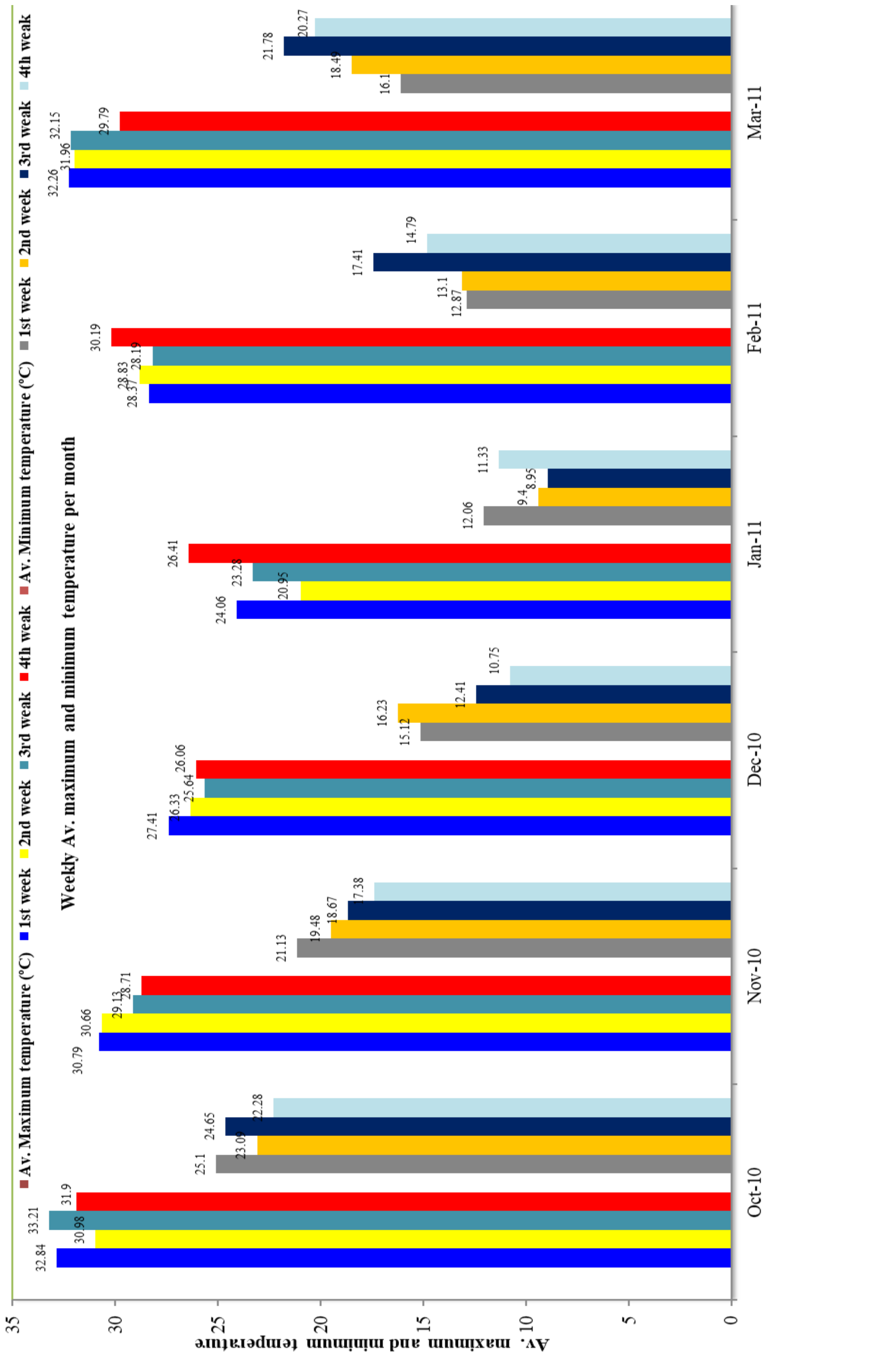

Figure 1: Weekly average maximum and minimum temperature shown on November/2010 – March/2011

Evaluation of yield components in reproductive stage

Miah and Pathan (1989) reported that early transplanting (5 December) was affected by cold at anthesis period and observed higher spikelet sterility with lower grain yield, longer growth period, shorter plants and panicles, and fewer panicles/hill. Singh *et al.* (2005) also reported that yield losses were ranged from 0.5 to 2.5 t/ha about 75% with low temperature in the reproductive stage, and happened incomplete pollen formation and subsequent floret sterility. Similar findings were consonance with the observation of Cruz *et al.* (2006) who found the reduced spikelet fertility in low temperature (17 °C) at the reproductive stage. Similar results were supported by Ye *et al.* (2009).

Relationship between yield and sterility percentage in cold temperature

Kabir *et al.* (2015) reported that the late established crop was attained quite safe with parallel high (day) temperature (31 - 35 ºC) and appeared at alleviating effect of low temperature. Similar results were reported by Biswas *et al.* (2008). Variation of high temperature as well as the variation of low temperature was found to have significant role in mitigating the effect of cool-injury (Kabir *et al.,* 2015). These findings are in accordance with the observation of Gomosta *et al.* (2001). Nishiyama (1978) and Heenan (1984) observed that spikelet sterility was increased in long duration of low temperature during the young microspore stage. Similar findings were supported by Yoshida (1981b). Biswas *et al.* (2011) suggested night temperature of 12 - 13 °C and day temperature of 28 - 29 °C as critical temperature during reproductive stage which reduced 50% of the original yield. Similar results were also reported by Farrell *et al.* (2006). Spikelet sterility was found at below critical low temperature for three days in reproductive stage, while severe damage in prevailing critical low temperature for more than 5-6 days as reported (BRRI, 2017).

Evaluation of different planting dates, plant height and maturity

The phenological variation of the seeding time and seedling age, and duration of life cycle of different varieties in vegetative phase at different dates of planting in the winter season were reported by Gomosta *et al.* (2001). These findings were in agreement with the observation of Vergara *et al.* (1976) who reported that the vegetative phase of rice was extended in low temperature. Stunting of growth and reduction in plant height resulted common symptom of cool injury in seedling, and highly correlated with weight, growth of shoot and root as reported by Yoshida (1981b). The stunting of growth in crop due to excessive cold is not uncommon as we have noticed in this study.

Based on the above findings, it may be concluded that the genotypes IR77496-31-2-1-3-1 and IR62266-42-6-2 were found to show good effect as tolerance to cold at the reproductive stage of the crop. IR77496-31-2-1-3-1 remarked the best result in terms of yield. This genotype might have the mechanism both of tolerance as well as avoidance. IR77496-31-2-1-3-1 was also found to produce significantly higher number of grain and lower percentage sterility that encounter the cold directly too. The yields of BRRI dhan36 and IR77496-31-2-1-3-1 signified avoidance mechanism as the yield level was significantly higher than another genotype BRRI dhan28. Obviously the significant relationship between temperature and yield for all the genotypes was observed except IR77496-31-2-1-3-1 in different planting dates.

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