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Research Article

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Morpho-physiological and phenological response of rice (*Oryza sativa* L.) genotypes to low temperature stress at reproductive stage

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ABSTRACT

The yearly changes in atmospheric temperature are projected to negatively affect food production in several locations. Rice exposure to low-temperature stress can decrease plant growth in different stages, notably during the reproductive period. A field experiment was conducted in ARS Gangavathi, Karnataka. The experiment laid out in factorial randomized block design where four different rice genotypes (GNV-10-89, GNV-1801, GNV-1108 and BPT-5204) transplanted under two different dates of transplanting D_1 (normal *Kharif*-15th September) and D_2 (late *Kharif*-30th September). The low temperature during the reproductive stage was 14.1°C which inhibited the morphological, physiological, phenological and yield traits of rice crop. All the observations were recorded at the flowering stage (95 DAT). The results revealed that morphological traits like plant height, number of green leaves, number of productive tillers, total dry matter, total leaf area and root length were high in D_1 than D_2 (101.6 & 99.76 cm, 21.5 & 16.1 hill^{-1}, 14.5 & 11.5 hill^{-1}, 29.0 &21.1 g hill^{-1}, 3.79 & 4.11 dm^2 hill^{-1} and 14.6 & 18.2 cm), physiological traits such as photosynthetic rate (14.55 & 13.45 µ mole CO_2 m^{-2} s^{-1}) and Transpiration rate (12.86 & 11.01 m mole H_2O m^{-2} s^{-1}) similarly phenological traits, DPI (80.6 & 90.5 days), DF (98.3 & 102.3 days), DPM (116.7 & 127.2 days) and DHM (124.7 & 135.4 days). Reproductive traits like pollen viability (91.3 & 87.4 %) and spikelet fertility (84.3 & 75.9 %) and grain yield (7744.8 & 6531.3 kg ha^{-1}). Among the genotypes GNV-10-89 (10270.9 kg ha^{-1}) recorded the higher grain yield and lower was observed in BPT-5204 (3937.5 kg ha^{-1}) these results conclude that the late *Kharif* transplanting was not suitable for this region as there was sharp drop-down of temperature (14.1°C) at a reproductive stage which leads to high spikelet sterility. By looking at the results obtained, among four genotypes GNV-10-89 recorded high grain yield followed by GNV-1108 these two genotypes are considered as moderately tolerant, GNV-1801 is moderately sensitive and BPT-5204 is sensitive to low-temperature stress.

Keywords: Low temperature stress, Rice crop, Reproductive stage, Phenological traits and Grain yield

INTRODUCTION

Energy is the sole prerequisite for maintaining the organism's structural integrity over its lifetime. A plant's ability to function normally and maintain its health can be hampered by several forms of stress such as salt, dryness, extreme high or low temperatures and heavy metals. The results of this study shed light on the effects of low temperature stress on the morpho-physiological and phenological characteristics and yield of rice crops. Extreme weather conditions are thought to be responsible for 18-43% of the yield changes between years (Vogel *et al*., 2019). The rice crop native to tropical and subtropical regions need temperature between 20°C to 40°C to grow reported by Sridevi and Chellamuthu (2015). According to Susanti *et al*. (2019) in a field experiment, rice spikelet sterility can reach 89.7% when exposed to low temperature during the flowering stage when compared to varieties that are resilient to the stress condition. Even though the best time to rice plant varies depending on the genotype, region and location, it is crucial to choose the right timing for sowing and transplanting to have a high grain yield (Deshmukh and Patel, 2013). It was also reported that cold stress delays phenological development and increases spikelet sterility, resulting in low yield (Farrell *et al*., 2001; Lee, 2001 and Gunawardena *et al*., 2003). All phenological stages of rice are impacted by exposure to cold temperature, which also results in decreased grain filling and grain yield. Low temperature during vegetative stage might result in sluggish growth, reduced seedling vigour, fewer seedlings, less tillering, higher plant mortality, prolonged growth periods and an earlier reproductive stage (Ali *et al*., 2006; Fujino *et al*., 2004). Low temperature stress has an impact on the phenology, spikelet sterility and yield of *Kharif* rice. Early seeding followed by regular sowing resulted in a noticeably better grain production. The maximum grain production among the cultivars was obtained by JGL-1798 (short duration), followed by JGL-384. When sown early, the long-duration variety BPT-5204 provided noticeably larger yields and when sowings were postponed, grain yields gradually decreased. Compared to minimum temperatures from panicle initiation to 50% flowering and 50% flowering to maturity, the minimum temperature at flowering was significantly and favourably linked with yield (Dakshina Murthy and Upendra Rao, 2010). The rice varieties used in this experiment BPT-5204 and GNV-1801 were long duration varieties whereas GNV-10-89 and GNV-1108 were short duration varieties.

The current investigation was carried out in Tunga Bhadra Command Area (TBCA), where farmers in the Gangavathi region were getting water later than farmers in other TBCA regions. As a result, paddy (rice) planting was delayed until late *Kharif.* To determine the impact of low temperature on late *Kharif* planting, we used two varieties with short durations and two varieties with long durations. In this experiment, the varieties BPT-5204, GNV-1801 (long duration), GNV-10-89, and GNV-1108 were employed (short duration). The reproductive stage of long duration varieties transplanted in late *Kharif* (30th September) experienced a sharp drop in temperature that is in the month of December the minimum temperature was 14.1°C which severely affected the grain filling stage of rice crop.

MATERIALS AND METHODS

To understand the morpho-physiological and phenological characterization of rice varieties for low temperature stress tolerance, a field experiment was conducted during the *Kharif* (15th September) and late *Kharif* (30th September) seasons of 2020-21 and 2021-22 at the Agricultural Research Station, Gangavathi, University of Agricultural Sciences, Raichur, Karnataka located at an altitude of 419 metres above mean sea level. Two factorial randomised block design was used for the field experiment, with factor one being the dates of transplanting and factor two being the varieties with three replications. For this field experiment, four distinct varieties (BPT-5204, GNV-1801, GNV-10-89, and GNV-1108) were chosen. These cultivars came from the University of Agricultural Sciences, Raichur, Karnataka's AICRP on Rice, Gangavathi Agricultural Research Station.

Abbreviations:

GNV - Gangavathi
AICRP - All India Coordinated Research Project
DAT- Days after transplanting
CD - Critical difference; SEm. - Standard error of the mean; CV - Coefficient of variation
DPI - days to panicle initiation; DF - days to 50% flowering; DPM - days to physiological maturity
DHM - days to harvestable maturity; ARS - Agriculture Research Station

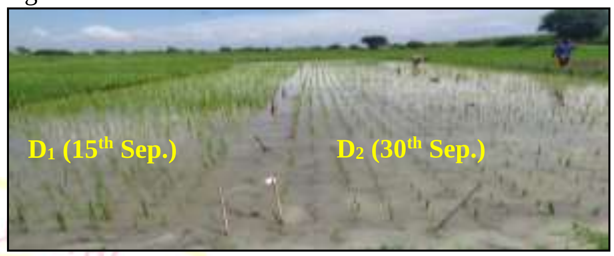

Plate 1. Transplanting of 25 days old paddy seedlings in the main field at two different dates *i.e.*, D_1 & D_2 (15th and 30th September) for the experimental year 2020-21

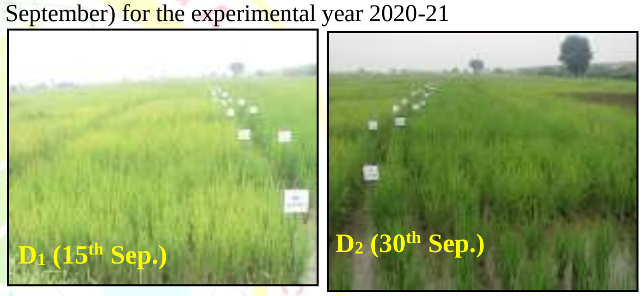

Plate 2. Crop at 65 DAT in D_1 and D_2 (15th and 30th September) for the experimental year 2020-2021

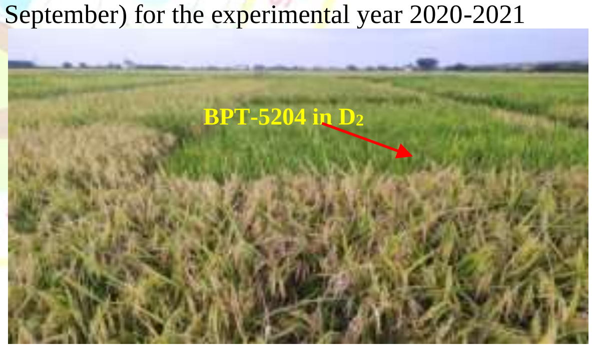

Plate 3. BPT-5204 in D_2 at 95 days after transplanting encounters the low temperature

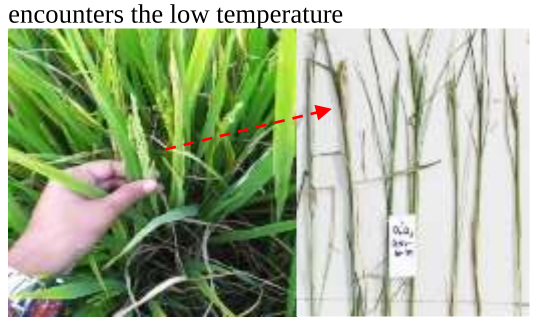

Plate 4. Incomplete panicle exsertion in BPT-5204 due to late *Kharif* planting (D_2)

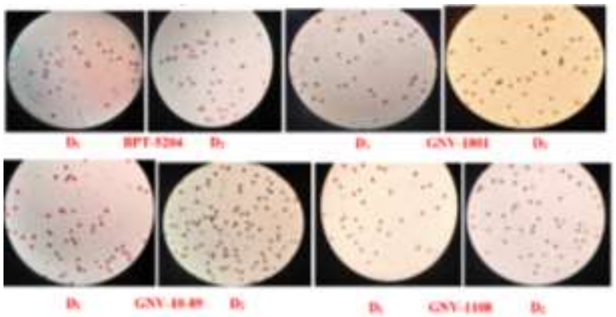

Plate 5. Pollen viability of different rice varieties in two dates of transplanting (D1 & D2) for the experimental year 2020-21

RESULTS AND DISCUSSION

Morphological traits

The data on morphological traits such as plant height, number of green leaves, number of productive tillers, total dry matter production, root length and total leaf area recorded at flowering stages (95 DAT) under two distinct transplanting dates and four varieties presented in the Table 1. With respect to dates of transplanting plant height, number of green leaves, number of productive tillers and total dry matter production were significantly higher in D_1 (101.6 cm, 21.5 hill^{-1}, 14.5 hill^{-1} and 29.1 g hill^{-1},) than D_2 (99.76 cm, 16.1 hill^{-1}, 11.5 hill^{-1} and 21.1 g hill^{-1}). Among the varieties GNV-10-89 showed higher plant height, productive tillers and total dry matter (111.8 cm, 16.0 hill^{-1} and 32.7 g hill^{-1}) which was accompanied by GNV-1108 (104.0 cm, 14.3 hill^{-1}, 26.9 g hill^{-1}). The lower plant height, number of productive tillers and total dry matter was observed in BPT-5204 (85.7 cm, 10.1 hill^{-1} and 18.2 g hill^{-1}). Number of green leaves, total leaf area and root length was higher in BPT-5204 (25.5 hill^{-1}, 5.07 dm^2 hill^{-1} and 18.1cm) this might be due to low temperature, reduced sunshine hours and cloudy weather leads to decreased transpiration rate and reduced senescence process. Among the interactions D_1V_3 showed higher plant height, number of productive tillers, total dry matter production (112.0 cm, 17.4 hill^{-1}, 39.4 g hill^{-1}) and D_2V_1 recorded the lower (85.1 cm, 8.9 hill^{-1}, 15.6 g hill^{-1}). Number of green leaves was higher in the interaction D_1V_1 (30.1 hill^{-1}) and lower in D_2V_4 (10.3 hill^{-1}) whereas, total leaf area and root length was higher in D_2V_1 (5.34 dm^2 hill^{-1} and 20.2 cm) and lower was observed in D_1V_4 (2.55 dm^2 hill^{-1} and 13.4 cm).

Seedling growth rate increases linearly between 22-31ºC temperatures. Critical low temperature required for shoot and root elongation about 12-16ºC therefore optimum transplanting date and suitable varieties may have considerable impact upon crop production. In the present experiment the plant height increased actively from 65 to 95 DAT but the marginal increase in plant height was observed from 95 DAT up to harvest. The maximum plant height was recorded in *Kharif* (D_1) than late *Kharif* (D_2) due to incidence of low temperature at late *Kharif* (30th September). The time of transplanting ensures the complete synchronization between vegetative and reproductive phases on one hand and climatic rhythm on the other hand. Therefore, the plant height recorded in the present experiment was in line with the findings of Kumar and Surendar (2019) they screened out 22 rice cultivars for low temperature stress tolerance through the physiological and biochemical responses the maximum plant height varied with different growth stages among 22 rice cultivars. The temperature drops down to 10°C during seedling establishment such low temperature significantly reduced seedling growth and establishment (Humphreys *et al.,* 1996). Due to low temperature stress reduced plant height was observed in BPT-5204 reported by Pradhan *et al*. (2017). Number of green leaves reduced from 65 DAT to harvest, in *Kharif* (D_1) number of green leaves were higher where as in late *Kharif* (D_2) number of green leaves recorded lower. The vegetative growth prolonged and the genotype BPT-5204 recorded more number of green leaves in late *Kharif* and thereafter declined due to the process of senescence at harvest. The results were in line with the findings of Kumar and Surendar (2019) who reported that, the number of green leaves per plant were more at 30 and 60 DAT in different varieties. Reyes *et al*. (2003) suggested that rice growth in the temperate regions was constrained by the limited period that favours growth where it needs optimum temperature between 25°C to 35°C and temperatures below this often result in poor seedling vigour. The optimum temperature required for tillering was 25ºC - 31ºC, tillering rate inhibited by low temperature due to which the period of tillering prolonged. The low temperature stress decreases the uptake of solutes by root owing to which water balance disturbed leading into more transpiration as compared to water absorption due to loss of water which resulted in leaf curling and reduced photosynthetic rate. In this experiment *Kharif* (D_1) recorded maximum number of productive tillers than late *Kharif* (D_2) at 95 DAT. Kuroki *et al*. (2007) stated that rice is a cold sensitive crop that has its origin in tropical or sub-tropical areas and low temperatures dramatically reduce its production and low temperature at the early stages of development inhibits seedling establishment due to which the crop establishment will be non-uniform. Among the varieties a greater number of productive tillers observed in GNV-10-89 followed by GNV-1108 because these two varieties showed low temperature stress tolerance whereas BPT-5204 and GNV-1801 recorded less number of productive tillers as they were low temperature stress sensitive varieties. The similar results were obtained by Kaneda and Beachell (1974) who noticed that, the types of low temperature effects on seedlings can be manifested as poor germination, slow growth and discolouration or yellowing, withering after transplanting, reduced tillering and stunted growth. Farzin *et al*. (2013) who found that rice plant was sensitive to low temperature stress. Maximum total dry matter production was recorded in GNV-10-89 at D_1 (*Kharif*) while the less was observed in BPT-5204 at D_2 (late *Kharif*). These results were in line with the findings of Aghaee *et al*. (2011)

found that, the quantitative changes of dry matter, were determined in cold sensitive rice genotype (Hoveizeh) in comparison with check genotype (IRCTN34, cold tolerant), treatment plants were exposed to 15/10°C (day/night) cold stress for two weeks and control plants were kept at 29/22°C (day/night) and 12 hours photoperiod. Dry matter accumulation decreased due to low temperature stress in both varieties. Cold tolerant genotype showed increased accumulation of total dry matter in rice seedlings where as cold-sensitive genotype showed less values. Higher leaf area was recorded in *Kharif* (D_1). However, lower leaf area reported in late *Kharif* (D_2). This might be due to the congenial environmental conditions *i.e.*, the average temperature (21-37 ºC) throughout the crop growth period and prolonged sunshine hours that prevailed during *Kharif* (D_1) transplanting date. Variation among the varieties in respect of leaf length, width and leaf area appeared due to genotypic variation. GNV-10-89 and GNV-1108 recorded higher leaf area at all growth stages. The decrease in the overall growth of rice plants due to changes in physical characteristics of the structural system of cells and alteration in the metabolic reactions that affect physiological processes. The reduction in leaf area subjected to low temperature stress under delayed transplanting in conformity with earlier studies (Nagasuga *et al*., 2011) the effect of low root temperature on rice growth in relation to dry matter production, root water uptake and leaf area. They found that, the low root temperature inhibited dry matter production of rice plants by decreasing the leaf area where the response of leaf area was affected by changes in plant water status. The higher root length was noticed in GNV-10-89 at D_1 (*Kharif*) at initial growth stages where as the lesser root length was observed in BPT-5204 at D_2 (late *Kharif*). Since the plant growth gradually advances the root length decreased in GNV-10-89 as it is a short duration genotype. Hence shoot length was increased whereas root length decreased significantly. BPT-5204 recorded maximum root length at 95 DAT due to the effect of low temperature, less humidity and lower sunshine hours the senescence process was slower. The similar results were obtained by Kumar and Surendar (2019) they found that among 22 rice varieties BPT-5204 recorded high root length.

Physiological traits

The result obtained on photosynthetic rate and transpiration rate at 95 DAT presented in the Table 1. The significantly higher photosynthetic rate and transpiration rate was recorded in D_1 (14.55 μ moles CO_2 m^{-2} s^{-1} and 12.86 m moles H_2O m^{-2} s^{-1}) as compared to D_2 (13.45 μ moles CO_2 m^{-2} s^{-1} and 11.01 m moles H_2O m^{-2} s^{-1}). Among four varieties, GNV-10-89 (15.20 μ moles CO_2 m^{-2} s^{-1} and13.64 m moles H_2O m^{-2} s^{-1}) recorded significantly maximum photosynthetic rate and transpiration rate respectively, which was on par with GNV-1108 (14.10μ moles CO_2 m^{-2} s^{-1} and 12.54 m moles H_2O m^{-2} s^{-1}) and the minimum photosynthetic rate was noticed in GNV-1801 (13.19 μ moles CO_2 m^{-2} s^{-1}) followed by BPT-5204 (13.52 μ moles CO_2 m^{-2} s^{-1}). The differences in photosynthetic rate and transpiration rate were not significant between interaction effect both in transplanting dates and varieties.

These results were in line with the findings of Ahmed *et al*. (2011) who reported reduction in photosynthetic efficiency and stomatal conductance and ultimately lower yield under variable weather conditions. Photosynthetic efficiency could be improved by exposure to favourable environments and optimizing transplanting date. The stress caused by low temperature could lead to reduced physiological activity of crop plants which reduces permeability of cell membrane in water uptake, in this study late *Kharif* transplanting showed reduced net photosynthesis this might be due to low temperature stress decreased metabolic activity of the root cells, earlier research showed reduced leaf growth and in turn the leaf area in many species of plant (Farooq *et al*., 2009). Among the varieties higher photosynthetic rate was seen in GNV-10-89 at critical growth stages due to high leaf area, favourable temperature, prolonged sunshine hours and photoperiod. BPT-5204 possessed relatively lower photosynthetic rate. The similar results were obtained by (Prasad *et al*., 1994; Ribascarbo *et al*., 2000) who found that, the cold stress in rice reduces the photosynthesis activity by reducing the chlorophyll content. Transpiration rate, an important indicator of physiological characters strongly influenced under continuously changing climatic scenarios like temperature, humidity and light intensity and crop internal factors including stomatal aperture and hydraulic status of plant. The present study revealed that higher transpiration rate led to water circulation and optimum photosynthetic efficiency which consequently increased yield in *Kharif* (D_1). Likewise, Li *et al*. (2004) revealed that, the low temperature deteriorated plant growth, chlorophyll content, net photosynthetic rate stomatal conductance, intercellular CO_2 and transpiration rate in zoysia grass. Genotype GNV-10-89 showed adaptability measures to cope stress and environmental constraints as compared to BPT-5204 and GNV-1801. Higher transpiration rate reflected in high dry matter and grain yield in GNV-10-89.

Phenological traits

The data with respect to number of days to PI (panicle initiation), FF (50 % flowering), PM (physiological maturity) and HM (harvestable maturity) presented in the Table 2. Late *Kharif* transplanting that is D_2 took a greater number of days (90.5 days, 102.3 days, 127.2 days and135.4 days) to PI, FF, PM and HM respectively was differed significantly from D_1 (80.6 days, 98.3 days, 116.7 days and 124.7 days). Among varieties GNV-10-89 (79.2 days, 88.3 days, 109.8 days and 118.9 days) took significantly less number of days for PI, FF, PM and HM respectively, which was on par with GNV-1108 (79.4 days, 89.2 days, 109.1 days and118.8 days), BPT-5204 (92.4 days, 114.8 days, 135.1 days and141.7 days) taken more number of days for PI, FF, PM and HM respectively, followed by GNV-1801 (91.2 days, 108.8

days, 133.8 days and 141.0 days). The influence of interactions was non-significant for days required to PI and FF whereas, PM and HM differed significantly where in D_2V_1 (138.5 days and 145.4 days) took a greater number of days to PM and HM and less number of days to PM and HM was noticed in the interaction D_1V_3 (102 days and 111.5 days). Delay in transplanting of *Kharif* rice (D_2) took more number of days to phenological characters such as days to panicle initiation, days to 50% flowering, days to physiological maturity and days to harvestable maturity as influenced by low temperature stress. Temperature is one of the major factors influencing crop growth, which cannot be manipulated under field conditions. In this study panicle initiation, 50% flowering, physiological maturity and harvestable maturity took more number of days in late *Kharif* (D_2) planting as compared to *Kharif* (D_1). According to Shi *et al*. (2021) reported chilling treatment (15ºC) at booting to flowering stage for 8 days, delayed flowering date by 5 days as compared to the control. The intensity and duration of low temperature at the booting and flowering stage affected the phenology and grain yield of rice. Low temperature stress lengthened the growth period of rice but decreased the grain yield by reducing the sink capacity. The varieties exposed to low temperature stress condition at booting and flowering stages reduced the spikelet fertility and the grain number per panicle, which led to considerable yield loss in delayed planting.

Reproductive traits

The data pertaining to pollen viability and spikelet fertility presented in Table 2 and differed significantly among the dates of transplanting, varieties and interactions. The transplanting date D_1 (91.3 % and 84.3 %) showed significantly higher pollen viability and spikelet fertility as compared to D_2 (87.4 % and 75.9 %). Among varieties GNV-10-89 (94.1 % and 85.7 %) showed higher pollen viability and spikelet fertility which was on par with GNV-1108 (91.3 % and 83.4 %).

Table 1. Effect of low temperature on morpho-physiological traits of rice varieties in two dates of transplanting at reproductive stage

Treatments	Plant height (cm)	No. of green leaves hill^{-1}	No. of productive tillers hill^{-1}	Total dry matter (g hill^{-1})	Total leaf area (dm^2)	Root length (cm)	Photosynthetic rate (µ mole CO_2 m^{-2} s^{-1})	Transpiration rate (m mole H_2O m^{-2} s^{-1})
	Days after transplanting (DAT) Pooled (2020-21 and 2021-22)							
	95 DAT	95 DAT	95 DAT	95 DAT	95 DAT	95 DAT	95 DAT	95 DAT
Transplanting dates								
D_1	101.6	21.5	14.5	29.0	3.79	14.6	14.55	12.86
D_2	99.76	16.1	11.5	21.1	4.11	18.2	13.45	11.01
S.Em.±	0.42	0.47	0.26	0.45	0.09	0.18	0.13	0.06
C.D. at 5%	1.29	1.43	0.81	1.37	0.28	0.55	0.39	0.19
Varieties								
V_1	85.7	25.5	10.1	18.2	5.07	18.1	13.52	10.03
V_2	102.6	19.5	11.8	22.3	4.14	16.9	13.19	11.52
V_3	111.8	16.9	16.0	32.7	3.74	15.7	15.20	13.64
V_4	103.9	13.3	14.3	26.9	2.84	14.9	14.10	12.54
S.Em.±	0.59	0.66	0.37	0.63	0.13	0.25	0.18	0.06
C.D. at 5%	1.82	2.03	1.14	1.94	0.39	0.77	0.55	0.20
Interactions								
D_1 V_1	86.3	30.1	11.2	20.8	4.80	16.1	14.33	10.69
D_1 V_2	102.6	21.4	13.3	25.5	4.14	15.0	13.59	12.53
D_1 V_3	112.0	18.3	17.4	39.4	3.66	14.1	15.61	14.62
D_1 V_4	103.7	16.2	16.0	30.2	2.55	13.4	14.67	13.60
D_2 V_1	85.1	20.7	8.9	15.6	5.34	20.2	12.71	9.37
D_2 V_2	102.7	17.6	10.4	19.1	4.14	18.9	12.79	10.50
D_2 V_3	111.6	15.4	14.5	26.0	3.83	17.4	14.80	12.65
D_2 V_4	104.2	10.3	12.5	23.6	3.11	16.4	13.53	11.52
S.Em.±	1.09	0.93	0.53	0.89	0.18	0.36	0.26	0.12
C.D. at 5%	NS	2.87	NS	2.74	NS	NS	NS	NS
C.V.	1.45	8.67	7.05	6.19	8.08	3.70	3.03	1.36

V1-BPT-5204; V2-GNV-1801; V3-GNV-1089; V4-GNV-1108; D2: (Late Kharif = 30-09-2020 & 21); D1: (Kharif = 15-09-2020 &21); F.W. - Fresh weight NS- Non-significant, Data analysed by using ICAR-WASP

Table 2. Effect of low temperature on phenological traits and yield of rice varieties in two dates of transplanting

Treatments	Days to Panicle initiation	Days to 50% flowering	Days to Physiological maturity	Days to Harvestable maturity	Pollen viability (%)	Spikelet fertility (%)	Grain yield (kg ha^{-1})
			Days after transplanting (DAT)				
			Transplanting dates				
D_1	80.6	98.3	116.7	124.7	91.3	84.3	7744.8
D_2	90.5	102.3	127.2	135.4	87.4	75.9	6531.3
S.Em.±	0.36	0.58	0.34	0.29	0.17	0.61	95.0
C.D. at 5%	1.09	1.79	1.04	0.89	0.54	1.86	290.9
			Varieties				
V_1	92.4	114.8	135.1	141.7	85.0	75.2	3937.5
V_2	91.2	108.8	133.8	141.0	87.2	76.0	5531.3
V_3	79.2	88.3	109.8	118.9	94.1	85.7	10270.9
V_4	79.4	89.2	109.1	118.8	91.3	83.4	8812.5
S.Em.±	0.50	0.83	0.48	0.41	0.25	0.86	134.4
C.D. at 5%	1.54	2.54	1.47	1.26	0.77	2.63	411.5
			Interactions				
D_1V_1	87.0	111.2	131.7	138.0	88.6	81.2	4625.0
D_1V_2	86.9	106.4	130.3	137.0	89.7	78.7	5958.3
D_1V_3	74.2	87.4	102.7	111.5	94.9	90.5	11000.0
D_1V_4	74.3	88.4	102.0	112.4	92.3	87.0	9395.9
D_2V_1	97.7	118.5	138.5	145.4	81.4	69.3	3250.0
D_2V_2	95.5	111.2	137.2	144.8	84.7	73.4	5104.2
D_2V_3	84.2	89.4	116.9	126.2	93.3	81.1	9541.7
D_2V_4	84.5	90.0	116.2	125.2	90.3	79.8	8229.2
S.Em.±	0.71	1.17	0.68	0.58	0.35	1.21	190.0
C.D. at 5%	NS	NS	2.08	1.78	1.08	NS	NS
C.V.	1.44	2.02	0.96	0.79	0.69	2.62	4.61

V1-BPT-5204; V2-GNV-1801; V3-GNV-1089; V4-GNV-1108; D2: (Late Kharif = 30-09-2020 & 21); D1: (Kharif = 15-09-2020 &21); F.W. - Fresh weight NS- Non-significant
Data analysed by using ICAR-WASP

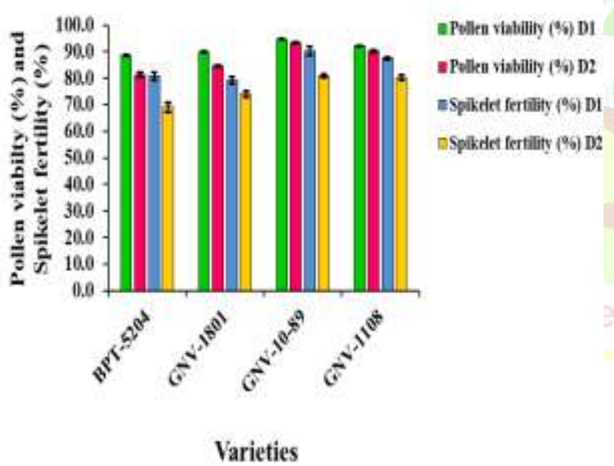

Figure 1. Effect of low temperature on pollen viability and spikelet fertility of rice varieties in two dates of transplanting
D_1-*Kharif* (15th September) & D_2-Late *Kharif* (30th September); standard error has been calculated and included in the graph

Significantly lower pollen viability and spikelet fertility was recorded in BPT-5204 (85.0 % and 75.2 %) followed by GNV-1801 (87.2 % and 76.0 %). The interaction effects showed significant differences where, the interaction between D_1V_3 (94.9 %) recorded significantly higher pollen viability whereas the interaction D_2V_1 (81.4 %) recorded less pollen viability. The influence of interactions effect showed non-significant differences with respect to spikelet fertility. Pollen viability, greatly contribute to the spikelet fertility these two components are directly proportional to each other. In this research higher pollen viability and spikelet fertility was recorded in *Kharif* (D_1) as compared to late *Kharif* (D_2).

Between varieties higher pollen viability and spikelet fertility was observed in GNV-10-89 and GNV-1108 as compared to BPT-5204 and GNV-1801) due to delayed planting where the reproductive stage affected by reduced temperature in December 3rd week (14.1°C) The fertilization stage from pollen maturation to the completion of fertilization is sensitive to low temperature. These results agreed with the findings of Satake (1989) who reported that, low temperature at the booting stage has also been reported to cause degeneration of young microspores and dissolution of tapetal cells, interrupting or decreasing the supply of nutrients from the anther walls to the pollens. According to Ye *et al*. (2009) yield losses due to cold temperature resulted in incomplete pollen formation and subsequent floret sterility also Andaya and Mackill (2003) reported that, low temperature affects rice cultivation mainly in two stages of development *i.e.*, seedling and booting. In these stages cold temperature has harmful effects on crop productivity.

Apart from the two critical stages, low temperature stress can also be manifested at different growth stages such as germination, seedling, vegetative, reproductive, and grain maturity. Suzuki *et al*. (2008) reported that the effects of cold stress at the reproductive stage of plants delay heading and result in pollen sterility, which is thought to be one of the key factors responsible for the reduction in grain yield of crops. Similarly, Suh *et al*. (2010) found that, the cold stress has many negative impacts on the productivity of rice cultivars like it reduces growth of seedling, weakens photosynthetic ability, reduces plant height, delays days to heading, reduces spikelet fertility and cause poor grain quality. According to Cruz *et al*. (2006) the effect of low temperature was investigated in six rice varieties at 17°C at two reproductive stages (microsporogenesis and anthesis). Low temperature tolerance was measured as the percentage of reduction in panicle exsertion and in spikelet fertility.

Grain yield (kg ha^{-1})

The results obtained with respect to grain yield were differed significantly among transplanting dates and varieties presented in the Table 2. The significantly higher grain yield was found in D_1 (7744.8 kg ha^{-1}) as compared to D_2 (6531.3 kg ha^{-1}). Among varieties the significantly more grain yield was obtained in GNV-1089 (10270.9 kg ha^{-1}) which was on par with GNV-1108 (8812.5 kg ha^{-1}) while the lower grain yield found in BPT-5204 (3937.5 kg ha^{-1}) followed by GNV-1801 (5531.3 kg ha^{-1}). The interaction effects were non-significant with respect to grain yield. Low temperature (< 20°C) delays rice seedling establishment, hampers tiller formation, affects flowering, causes panicle sterility and finally leads to lower grain yield (Hussain *et al*., 2019). Late *Kharif* (D_2) recorded the lower grain yield as compared to *Kharif* (D_1). BPT-5204 and GNV-1801 recorded less grain yield as compared to GNV-10-89 and GNV-1108. These results were in line with the report of Kumar and Surendar (2019) in their experiment they used 22 rice varieties including BPT-5204 rice seedlings were transplanted in the main field during late *Kharif* season. BPT-5204 showed lesser grain yield compared to all remaining varieties due to the effect of low temperature in delayed planting. Wainaina *et al*. (2015) also evaluated eight NERICA rice varieties for cold tolerance at reproductive stage and compared with their parents and three Japanese standard rice varieties over 3 years. Cold tolerance was evaluated based on the filled grain ratio (FGR) after cold water irrigation. NERICA 1, 2 and 7 showed significantly better performance than NERICA 3 and 4, while NERICA 6, 15 and 16 performed poorly under cold water irrigation. The Japanese varieties Koshihikari (tolerant) and Ozora (moderately tolerant) were more affected by cold water irrigation than NERICA 1, 2 and 7. According to (Shah *et al*. 2011) due to environmental constraints, it is estimated that rice yield will decline by 41% through the end of this century.

CONCLUSION

On the basis of above findings, it can be concluded that the overall physiological performance of rice crop in relation to morpho-physiology and phenology was affected with delayed planting. Low temperature stress resulted in reduced prolonged vegetative growth and more chaffy grains in the BPT-5204 genotype. Based on major growth parameters and grain yield affected in late *Kharif* planting the four rice varieties used in this experiment were categorized into sensitive and tolerant to low temperature stress such as GNV-10-89 and GNV-1108 moderately tolerant, GNV-1801 moderately sensitive and BPT-5204 sensitive to low temperature stress especially at reproductive stage.

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