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EFFECT OF LOW TEMPERATURE STRESS ON PHOTOSYNTHESIS, TOTAL SOLUBLE SUGARS, GRAIN FILLING RATE AND YIELD IN RICE (*ORYZA SATIVA* L.)

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SUMMARY

A field experiment with 15 rice (*Oryza sativa* L.) genotypes was conducted during *kharif* (rainy) season of 2001 to understand the photosynthetic basis of productivity under low temperature conditions in hills. Exposure of rice genotypes to low temperature conditions (mean temperature $<18^{0}$C and minimum temperature $<12^{0}$C) during reproductive phase was made by altering the dates of planting i.e. normal planting (transplanting date 25th June) and late planting (transplanting date 25th July). It was observed that the rates of photosynthesis and canopy photosynthesis showed significant positive association with grain yield during grain filling stage (15 days after anthesis) under normal planting and poor association under late planting. A significant reduction in rates of photosynthesis, canopy photosynthesis, and level of total chlorophyll was observed at grain filling stage under low temperature condition. Besides, a reduction in the grain-filling rate under late planting was also seen among rice genotypes. A significant enhancement in the level of total soluble sugars (TSS) in the flag leaf (L) while slight reduction in soluble sugars in panicle peduncle (P) was noted among rice genotypes exposed to low temperature condition. The total soluble sugars in the leaf showed significant negative association with photosynthesis rate. Moreover, highly significant positive association of harvest index (HI) with grain yield (r = 0.843) under late planting indicated that the low temperature reduced the partitioning of photoassimilates resulting in poor yield. Three advance lines of rice *viz*. VL-94-3288, VL-98-3894 and VL-98-3895 proved their cold tolerance efficiency > 80%.**

***Key words*: Chlorophyll, cold tolerance, grain filling, low temperature stress, photosynthesis, rice, total soluble sugars, yield**

INTRODUCTION

Low temperature is a major constraint in rice (*Oryza sativa* L.) production in the hilly regions. In Uttaranchal hills, spring sown rice crop faces cold stress during the seedling stage while rainy season sown rice experiences chilling temperature during reproductive phase (Tondon 1979). Symptoms of chilling injury include poor germination, stunted growth, reduced photosynthetic capacity, discoloration and necrosis, poor panicle exertion, abnormal ripening and increased disease susceptibility which ultimately result in yield reduction (Hamdani 1979). The potential yield of a crop, to a great extent, is determined by photosynthesising capacity of plant (Yoshida 1972). A high rate of photosynthesis is always associated with higher productivity, unless sink capacity is limiting (Evans 1975). A wide variation in photosynthesis rate and productivity among the rice genotypes has been reported (Janardhan *et al*. 1983, Basuchaudhuri and Dasgupta 1987, Ishil 1988, Sharma and Singh 1994, Padamja *et al*. 2003). Response of plants to biotic and abiotic stresses is also reflected by a change

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in their photosynthetic rates and total soluble sugars accumulation (Bruggemann *et al*. 1994, Conocono *et al*. 1998, Kumar 2000). Kumar (2002) reported the reduction in rate of photosynthesis and yield among rice genotypes under low temperature conditions. Therefore, an attempt has been made in the present study to correlate the levels of total soluble sugar in leaf and panicle peduncle with photosynthesis under low temperature conditions.

MATERIALS AND METHODS

A set of 15 rice (*Oryza sativa* L.) genotypes (5 varieties (checks) and 10 advance lines) viz. VL Dhan 81, VL Dhan 206, Barkat, China 4, Thapachini, VL-93-2767, VL-94-3288, VL-96-3610, VL-97-3653, VL-97-3657, VL-97-3361, VL-98-3894, VL-98-3895, VL-98-4009, VL-98-4034 was sown in nursery bed at two dates of sowing i.e. normal (25 May) and one month late (25 June) during kharif (rainy) season (2001). Thereafter, thirty days old seedlings of above stated genotypes were transplanted in well puddled fields at two dates i.e. normal planting (25 June) and late planting (25 July) to expose the reproductive phase of genotypes to low temperature conditions. The crop sown on 25th may was considered normal because its sowing was done following the recommended optimum date for sowing and the terminal phase of this normal sown crop did not coincide with low temperature condition at this altitude. The experiment was laid out in factorial randomized block design with three replications at experimental farm, Hawalbagh (1250 m amsl, $79^o 40'$E and $29^o 56'$N) of Vivekanada Parvatiya Krishi Anusandhan Sansthan (ICAR), Almora (U.A.). All the recommended cultural practices were followed to raise a healthy crop. Weather conditions during the course of investigations were recorded. Under late planting, grain-filling phase of rice crop coincided with very low night temperature coupled with negligible rains.

The leaf photosynthesis rate (Pn) (μ mol $CO_2/m^2/s$), and stomatal conductance (Cs) (m mol/m^2/s) were measured on flag leaf during reproductive phase at 15 days after anthesis (15 DAA) using portable photosynthesis system (CIRAS-1, U.K.) between 10-12 hr on cloudless days (photosythetically active radiation approximately 1200 μmol/m^2/s). Leaf area was measured at 15 DAA with the help of Leaf area meter (LI-COR 3000 A, USA). Canopy photosynthesis (CPn) was estimated 15 DAA by following the method as described by Kumar (2002). Level of total soluble sugars were determined in plant tissues (flag leaf and panicle peduncle) at 15 DAA by the method of Loewus (1952). Chlorophyll content of the flag leaf was estimated as per Hiscox and Israelstam (1978) and calculated according to the formula given by Arnon (1949). For the determination of grain filling rate, around 20 panicles per plot were tagged at anthesis and then after every five days interval two panicles per plot were collected and their spiklets, seed number and seed weight after drying were determined. Grain filling rate was estimated as the gain in seed weight per day. Cold tolerance efficiency (%) of the genotypes was calculated as described by Kumar (2002). Total dry matter, yield and its attributes were recorded at harvest. Data obtained were analyzed by adopting standard statistical methods (Panse and Sukhatme 1967). Correlations were tested following Z test (Snedecore and Cochran 1967).

RESULTS AND DISCUSSION

Significantly lower rates of photosynthesis and canopy photosynthesis were obtained under late planting (low temperature conditions) compared to normal planting at 15 day after anthesis during grain filling. Low temperature conditions below critical level (mean temperature less than 18 ^{0}C and minimum temperature less than 12 ^{0}C) coincided with grain filling phase under late planting (Fig. 1) resulting in drastic reduction in rates of photosynthesis and canopy photosynthesis. The rates of photosynthesis recorded during grain filling phase

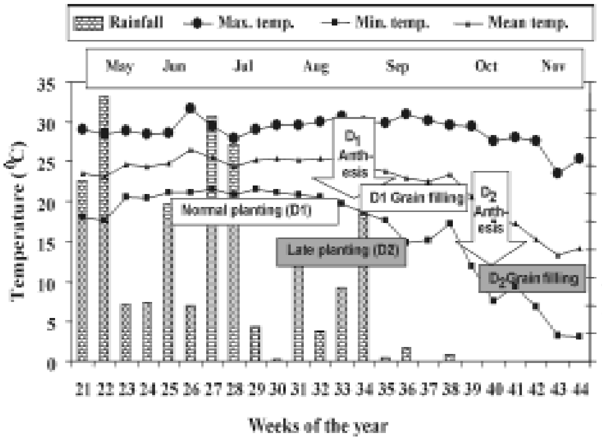

Fig. 1. Weather condition during the course of investigation

under normal and late (low temperature) plantings ranged between 15.90 to 20.43 and 8.53 to 19.03 µmol/m^2/s respectively (Table 1). Similarly canopy photosynthesis under normal and late plantings varied between 39.50 to 85.34 and 23.65 to 39.81 µmol/m^2/s respectively (Table 1). The significant variations in photosynthesis rates amongst the genotypes were due to their genetic differences. Similar observations were recorded earlier amongst the genotypes of rice under normal (Basuchaudhuri and Dasgupta 1987, Sharma and Singh 1994) and low temperature conditions (Kumar 2002). Stomatal conductance (Cs) at grain filling stage under normal and low temperature ranged between 1222.00 to 9999.00 and 405.00 to 7722.67 m mol/m^2/s respectively. Similar genotypic variations in terms of stomatal conductance were also observed earlier in rice (Tsunodo and Fukoshima 1986). Grantz (1989) also reported the reduction in photosynthesis and stomatal conductance in field-grown sugarcane under cool temperature. Reduction in stomatal conductance (Cs) under low temperature probably took place due to increase in level of ABA (Chen *et al*. 1983) which adversely modulates stomatal behaviour (Jensen *et al*. 1996). Stomatal conductance exhibited the significant

Table 1. Rate of photosynthesis, canopy photosynthesis, total chlorophyll and total soluble sugars content among rice genotypes during grain filling stage at 15 days after anthesis under normal (D1) and late planting (D2) conditions.

Genotypes	**Photosynthesis rate (µmol $m^{-2}s^{-1}$)**		**Canopy photosynthesis (µmol m^{-2}/s^{-1})**		**Total chl. (mg g^{-1} fw)**		**Total soluble sugar (mg g^{-1} fw)**					
							Flag leaf (L)		**Panicle peduncle (P)**		**Ratio (L/P)**	
	D_1	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**
VL Dhan 81	17.43	11.79	45.47	26.10	2.26	1.43	3.17	10.43	1.61	1.88	1.97	5.55
VL Dhan 206	19.03	11.67	58.59	26.35	2.41	1.55	1.84	9.10	2.74	1.18	0.67	7.71
Barkat	19.70	19.03	39.50	32.92	2.83	1.80	1.79	8.77	1.19	1.60	1.50	5.48
China 4	16.27	8.60	56.85	25.03	1.76	1.27	2.06	9.19	2.85	0.95	0.72	9.67
Thapachini	17.17	9.57	41.40	28.28	3.18	1.63	2.99	7.37	1.21	1.00	2.47	7.37
VL 93-2767	19.27	11.13	52.52	31.00	2.29	1.67	3.35	7.52	1.10	1.37	3.05	5.49
VL 94-3288	17.93	9.57	57.31	28.38	2.57	2.05	1.29	8.52	1.26	1.89	1.02	4.51
VL 96-3610	20.13	12.67	66.76	32.56	2.71	1.53	2.12	7.37	1.06	0.72	2.00	10.24
VL 97-3653	19.10	13.20	70.88	36.71	2.85	1.59	3.70	9.58	1.07	1.76	3.46	5.44
VL 97-3657	20.43	9.70	57.22	25.83	2.26	1.82	3.23	6.89	1.95	0.89	1.66	7.74
VL 97-3861	19.57	11.67	85.34	23.66	2.55	2.17	2.42	8.30	1.71	1.73	1.42	4.80
VL 98-3894	18.50	9.03	59.70	35.58	2.87	1.68	1.36	8.09	1.28	1.94	1.06	4.17
VL 98-3895	18.57	10.87	65.63	39.81	3.19	1.61	1.24	8.91	1.10	1.61	1.13	5.53
VL 98-4009	15.90	8.53	67.62	37.36	1.86	1.54	5.71	9.07	4.37	1.08	1.31	8.40
VL 98-4034	17.20	16.03	46.19	23.65	2.38	1.51	1.81	11.87	3.00	1.10	0.60	10.79
Mean	**18.41**	**11.54**	**58.07**	**30.21**	**2.53**	**1.66**	**2.54**	**8.73**	**1.83**	**1.34**	**1.60**	**6.86**
CD at 5 %												
Treatment(T)	**0.77**		**2.44**		**0.12**		**0.628**		**0.162**		**0.780**	
Genotypes(G)	**2.11**		**6.90**		**0.33**		**0.230**		**0.059**		**0.285**	
T x G	**2.98**		**9.46**		**0.47**		**0.888**		**0.229**		**1.102**	

D_1 = Normal sowing (control) (T_1); D_2 = Late sowing (Low temperature condition) (T_2)

positive association (r = 0.911**) with rate of photosynthesis (Fig. 2) as it controls the gaseous exchange in leaf, and therefore lowering of Cs ultimately resulted into reduction in photosynthesis rates under low temperature conditions.

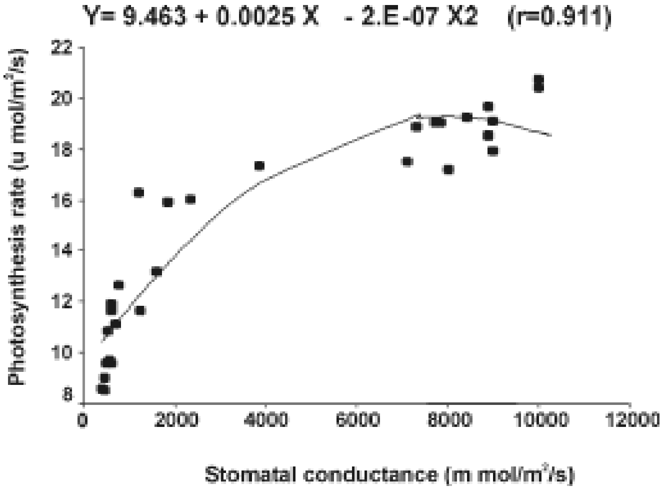

Fig. 2. Relationship between photosynthesis rate and stomatal conductance in flag leaf of rice (n= 30)

The content of total chlorophyll recorded at grain filling stage under normal planting, ranged between 1.76 to 3.19 mg / g. f. wt. while under late planting (low temperature) varied between 1.27 to 2.17 mg/g f. wt. (Table 1). The significant differences in contents of photosynthetic pigments amongst the genotypes might be due to variations in their genetic constitution. The present findings on reduced contents of photosynthetic pigments due to low temperature stress are in conformity with earlier reports (Wang *et al.* 1986, Kumar *et al.* 2002). Photosynthetic pigments are the essential part of photosynthetic machinery and consequently reduction in their contents also resulted in lower rates of photosynthesis under low temperature conditions. Under normal conditions comparatively higher rates of photosynthesis were associated with relatively higher levels of photosynthetic pigments.

The level of soluble sugars in flag leaf and peduncle estimated at 15 DAA varied significantly amongst different genotypes under both conditions. The level of total soluble sugars in flag leaf (L) and panicle peduncle (P) and their ratio (L/P) estimated at grain filling stage under normal planting, ranged between 1.24 to 5.71; 1.06 to 4.37 mg /g f. wt. and 0.60 to 3.46 respectively (Table 1). Similarly, level of total soluble sugars in flag leaf (L) and panicle peduncle (P) and their ratio (L/P) at grain filling under late planting (low temperature) varied between 6.89 to 11.87; 0.89 to 1.94 mg/g f. wt. and 4.17 to 10.79 respectively (Table 1). Enhancement in the level of total soluble sugars in leaf under low temperature stress is in agreement with earlier report of Bruggemann *et al.* (1994). Significant increase in the ratio of total soluble sugars concentration in flag leaf and panicle peduncle (L/P) under low temperature condition indicated that under low temperature partitioning/ translocation of soluble carbohydrates was adversely affected. Accumulation of total soluble sugar in flag leaf may be due to poor utilization of assimilates in the sink (Bruggemann *et al.* 1994). Total soluble sugars estimated in flag leaf showed the significant negative association (r = -0.751**) with photosynthesis rate (Fig. 3) which suggests that increase in level of total soluble sugars in leaves suppressed the photosynthesis under low temperature conditions as accumulation of soluble carbohydrates is known to suppresses photosynthesis by reducing phosphate cycling and depleting ATP levels in the chloroplast (Labate *et al.* 1990).

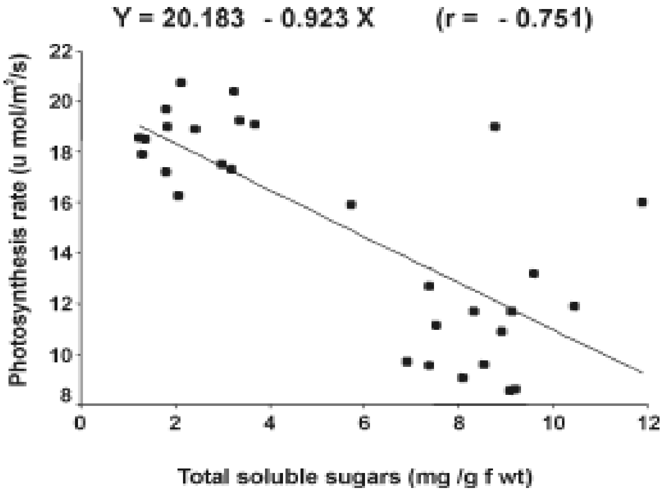

Fig. 3. Relationship between photosynthesis rate and total soluble sugar in flag leaf of rice (n= 30)

Genotypic differences in grain filling rates were obtained among rice genotypes under both normal and late planting conditions (Table 2). The maximum grain filling rates under both normal and late planting conditions were found at 15 days after anthesis (Table 2).

Table 2. Grain filling rates (mg/seed/d) among rice genotypes during grain filling stage under normal (D_1) and late planting (D_2) conditions.

Genotype	Grain filling rate (mg seed^{-1} d^{-1}) at different days after anthesis													
	5		10		15		20		25		30		35	
	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
VL Dhan 81	0.75±0.08	0.61±0.01	1.14±0.04	0.54±0.02	1.44±0.04	0.67±0.01	0.74±0.03	0.45±0.06	0.26±0.02	0.28±0.07	0.26±0.01	0.14±0.01	0.07±.0.03	0.090.01
VL Dhan 206	0.77±0.03	0.50±0.01	1.05±0.06	0.66±0.01	1.19±0.09	0.80±0.02	0.91±0.01	0.51±0.01	0.34±0.02	0.19±0.00	0.25±0.01	0.19±0.01	0.18±0.01	0.13±0.01
Barkat	0.78±0.03	0.73±0.01	0.79±0.05	0.73±0.01	1.24±0.08	1.09±0.01	0.75±0.02	0.29±0.01	0.46±0.01	0.31±0.01	0.39±0.01	0.33±0.01	0.13±0.01	0.08±0.00
China 4	0.72±0.04	0.45±0.07	0.92±0.06	0.34±0.02	1.22±0.03	0.45±0.01	0.61±0.07	0.74±0.01	0.42±0.03	0.55±0.03	0.26±0.01	0.25±0.04	0.18±0.02	0.01±0.00
Thapachini	0.76±0.07	0.61±0.01	1.21±0.03	0.66±0.01	1.24±0.04	0.77±0.01	0.98±0.01	0.43±0.01	0.36±0.01	0.20±0.01	0.30±0.01	0.18±0.02	0.06±0.01	0.06±0.02
VL 93-2767	0.61±0.03	0.60±0.02	1.13±0.07	0.97±0.01	1.18±0.05	1.16±0.02	0.93±0.03	0.51±0.03	0.72±0.01	0.08±0.02	0.25±0.01	0.21±0.01	0.16±0.01	0.06±0.03
VL 94-3288	0.84±0.02	0.63±0.01	1.20±0.01	0.60±0.04	1.61±0.02	0.77±0.04	0.38±0.03	0.47±0.01	0.45±0.02	0.42±0.02	0.16±0.05	0.32±0.01	0.07±0.04	0.20±0.01
VL 96-3610	0.90±0.05	0.44±0.01	0.88±0.08	0.66±0.01	1.26±0.8	0.87±0.01	1.05±0.02	0.92±0.02	0.42±0.02	0.90±0.01	0.39±0.01	0.43±0.01	0.32±0.02	0.00±0.00
VL 97-3653	0.87±0.02	0.68±0.01	0.85±0.04	0.57±0.01	1.20±0.03	0.69±0.01	0.94±0.05	0.60±0.01	0.45±0.01	0.48±0.02	0.48±0.03	0.40±0.02	0.01±0.04	0.19±0.01
VL 97-3657	0.84±0.02	0.21±0.02	1.03±0.01	0.80±0.02	1.21±0.05	1.15±0.04	0.82±0.04	0.65±0.02	0.34±0.02	0.37±0.03	0.25±0.09	0.16±0.01	0.15±0.06	0.11±0.01
VL 97-3861	0.89±0.04	0.63±0.01	1.06±0.09	0.68±0.02	1.09±0.05	0.77±0.02	1.18±0.02	0.55±0.01	0.67±0.01	0.36±0.01	0.09±0.01	0.04±0.02	0.04±0.02	0.01±0.00
VL 98-3894	0.83±0.08	0.61±0.01	0.95±0.02	0.76±0.02	1.49±0.02	0.94±0.01	0.89±0.03	0.79±0.01	0.44±0.03	0.64±0.03	0.35±0.03	0.39±0.08	0.20±0.01	0.08±0.01
VL 98-3895	0.93±0.07	0.45±0.01	1.20±0.05	0.68±0.01	1.51±0.05	0.71±0.01	0.53±0.07	1.03±0.01	0.42±0.02	0.64±0.02	0.29±0.02	0.38±0.02	0.06±0.02	0.11±0.01
VL 98-4009	0.89±0.03	0.47±0.01	0.95±0.01	0.66±0.02	0.97±0.02	1.05±0.02	0.61±0.01	0.65±0.01	0.43±0.01	0.24±0.03	0.31±0.01	0.23±0.00	0.14±0.02	0.14±0.01
VL 98-4034	0.94±0.09	0.55±0.01	0.99±0.03	0.53±0.06	1.43±0.03	0.55±0.03	0.91±0.03	0.77±0.01	0.10±0.01	0.40±0.02	0.11±0.01	0.16±0.02	0.07±0.02	0.18±0.01
Mean	**0.82**	**0.54**	**1.02**	**0.66**	**1.29**	**0.83**	**0.82**	**0.62**	**0.41**	**0.40**	**0.29**	**0.25**	**0.13**	**0.10**

D_1 = Normal sowing (control)(T_1); D_2 = Late sowing (Low temperature condition)(T_2) ± = Standard deviation

However, grain-filling rate under low temperature conditions was reduced drastically reduced than normal planting indicating that under low temperature partitioning of dry matter into economic sink was adversely affected.

Amongst the rice genotypes total dry matter (TDM), panicle weight, grain yield, test weight, grain sterility and HI ranged between 94.9 to 156.2 q/ha, 468.6 to 833.6 g/m^2, 42.2 to 71.2 q/ha, 24.0 to 31.3 g, and 13.6 to 31.7 (%) and 37.4 to 49.9 (%) respectively under normal planting (Table 3). Similar, genotypic variations in TDM and yield components were also observed earlier among rice genotypes (Ishii 1988, Kumar 2002). Under late planting (low temperature condition) genotypic variations in terms of total dry matter, panicle weight, grain yield, test weight, grain sterility and HI varied between 85.2 to 136.7 (q/ha), 340.1 to 580.8 (g/m^2), 18.9 to 55.9 (q/ha) 19.0 to 25.7 (g), 23.1 to 72.6 (%) and 15.8 to 42.1 (%) respectively (Table 3). Cold tolerance efficiency (%) among rice genotypes was estimated between the ranged from 40.99 to 85.74 (%). Three genotypes among the advance lines namely VL-94-3288, VL-98-3894 and VL-98-3895 proved their cold tolerance efficiency > 80% and were identified as promising cold tolerant genotypes (Table 3).

Table 3. Total dry matter (TDM), yield attributes and cold tolerance efficiency (CTE) among rice genotypes under normal (D_1) and late planting (D_2) conditions

Genotype	**TDM (q ha^{-1})**		**Panicle wt. (gm^{-2})**		**Yield (q ha^{-1})**		**Test wt. (g)**		**Grain sterility (%)**		**HI (%)**		**CTE (%)**
	D_1	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	**D_1**	**D_2**	
VL Dhan 81	116.35	99.74	604.94	492.50	55.86	35.28	27.67	23.00	15.03	44.21	47.98	35.52	63.16
VL Dhan 206	126.04	96.09	652.54	405.52	59.99	29.55	26.67	22.33	18.18	52.08	47.45	31.29	49.26
Barkat	94.86	85.20	468.60	481.41	42.16	32.22	27.00	22.67	20.91	36.11	45.57	37.88	76.42
China 4	122.88	119.68	550.56	349.75	46.08	18.89	24.00	19.00	31.67	69.03	37.37	15.82	40.99
Thapachini	120.92	102.86	573.50	509.05	53.57	42.10	25.67	23.67	13.58	32.22	44.17	40.80	78.59
VL 93-2767	119.25	105.96	598.63	536.66	55.94	40.09	25.33	23.00	13.78	37.67	46.87	41.60	71.67
VL 94-3288	119.60	119.85	631.95	580.79	58.87	47.01	27.00	25.33	14.41	34.94	49.17	39.34	79.85
VL 96-3610	134.75	115.45	680.19	502.12	68.12	36.75	31.33	25.00	14.32	51.41	49.87	31.88	53.95
VL 97-3653	135.02	107.38	745.79	545.62	67.88	43.17	26.33	25.67	21.31	47.73	47.98	40.26	63.60
VL 97-3657	128.37	109.99	684.13	537.63	62.65	43.75	26.67	24.33	17.67	40.72	48.81	39.88	69.83
VL 97-3861	156.18	118.98	833.61	577.88	71.18	38.74	26.67	22.33	18.32	50.79	45.50	32.39	54.43
VL 98-3894	138.98	132.03	705.36	683.10	65.20	55.90	27.67	24.33	17.11	23.05	46.92	42.05	85.74
VL 98-3895	134.35	128.07	685.84	627.06	56.86	50.56	29.33	24.33	24.63	34.66	46.89	39.32	80.43
VL 98-4009	140.03	136.72	584.36	340.09	42.21	23.03	25.67	22.67	51.71	72.57	28.74	16.69	42.40
VL 98-4034	124.37	96.71	632.38	457.11	57.07	33.34	27.00	23.00	22.06	54.41	46.04	34.81	58.42
Mean	**127.46**	**111.65**	**642.16**	**508.42**	**57.58**	**38.03**	**26.93**	**23.38**	**20.98**	**45.44**	**43.29**	**34.64**	**64.58**
CD at 5 %													
Treatment(T)	**5.47**		**32.14**		**2.85**		**0.35**		**2.18**		**1.75**		
Genotypes(G)	**14.98**		**88.01**		**7.81**		**0.96**		**5.97**		**4.78**		
T x G	**NS**		**124.46**		**11.04**		**1.36**		**8.45**		**6.76**		

D_1 = Normal sowing (control) (T_1); D_2 = Late sowing (Low temperature condition)(T_2)

Correlation analysis (Table 4) revealed that rate of leaf photosynthesis and canopy photosynthesis recorded during grain filling phase at 15 days after anthesis showed significant association with grain yield under normal planting. The results are in the agreement with earlier reports (Murthy *et al.* 1991, Sharma and Singh 1994). However, under late planting conditions at 15 days after anthesis (Fig. 1) rates of leaf photosynthesis and canopy photosynthesis exhibited poor association with grain yield. Further, harvest index had a significant positive association with grain yield under low temperature condition only. Ratio of total soluble sugars in leaf versus panicle peduncle (L/P) also exhibited significant negative association with yield under low temperature condition only, which in turn suggested that under low temperature partitioning of photosynthates, was slow or limited. In contrast, under normal planting partitioning of photoassimilates was not a limiting factor (Yoshida 1972, Evans 1975).

Table 4. Relationship between grain yield and physiological traits in rice under normal (D_1) and late planting (D_2) conditions.

Physiological traits	Correlation coefficient (r) with grain yield		
	Normal planting (D_1)		Late planting (D_2)
TDM	0.602**	# #	0.211
Panicle wt.	0.894**	# #	0.964**
HI	0.469	# #	0.848**
Test wt.	0.452	# #	0.760**
Pn (Grain filling)	0.588*	# #	0.121
CPn (Grain filling)	0.558*	#	0.333
Ratio of TSS (L/P)	0.230	# #	-0.622*
Pn (Grain filling) vs. Cs	0.824**	#	0.861**

# $P < 0.05$; # # $P < 0.01$ indicated that 'r' in D_1 & D_2 differ significantly following Z test

*Significant at P=0.05 (r=> 0.514) ** Significant at P=0.01 (r=> 0.641)

There was a significant shift in correlation values under low temperature conditions for all the characters. The highly significant positive correlation of grain yield with TDM, Pn and Cpn became non significant under low temperature while the non significant relationship of grain yield with HI, test weight and ratio of TSS (L/P) under normal condition became positively significant for yield with HI and test weight and significant negative correlation with ratio of TSS (L/P) under cold conditions in rice plant. The associations of grain yield with panicle weight and photosynthesis rate with stomatal conductance though positive under normal conditions, became stronger and significantly different under cold conditions. Hence it is concluded that under cold condition, the association of yield with other characters changes significantly. Among them the association of harvest index, test weight and ratio of total soluble sugar (L/P) with yield become more important while association of total dry matter, Pn, CPn with yield become less important.

Cold tolerance efficiency exhibited significant negative association with ratio of total soluble sugars (TSS) in flag leaf versus panicle peduncle (L/P) (r= -0.640*) and grain sterility (r =-0.962**) and significant positive association with harvest index (r = 0.868**), panicle weight (r = 0.815*) and test weight (r= 0.586*). Significant associations of cold tolerance with harvest index and grain sterility are in conformity of earlier report of Kumar (2002). Chlorophyll content though showed positive association with cold tolerance but were not significant statistically. Present findings suggested that grain sterility, harvest index, panicle weight, and ratio of total soluble sugars in flag leaf versus in panicle peduncle (L/P) may be considered as the criteria to select the cold tolerant rice genotypes in the hilly areas.

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