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Terminal heat stress modulates growing degree days, heat use efficiency and yield stability index in *brassica juncea*

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ABSTRACT

An experiment was planned to visualize the impact of terminal heat stress on yield potentials of late sown mustard cultivars under the changing climatic conditions. A set of fifteen B. juncea genotypes were evaluated at two planting dates during two winter seasons. Late planted genotypes faced heat stress during post anthesis/seed filling stage which negatively influenced the movements of photosynthates to developing sinks thus inhibiting synthetic processes, lowering seed weight and seed yield and may even hamper seed quality. Onset of flowering and siliquing were delayed but the completion of flowering and siliquae formation was earlier in the late planted genotypes. Seed filling was impeded by high temperature in late planting causing ≥50% decline in seed yield. Average accumulated growing degree days (AGDD) for phenological stages were higher in normal sown than the late sown crop. AGDD witnessed an increasing trend for flowering and fruiting behaviour in both the sowing dates. However, 50% flowering in late sown crop took 4 accumulated GDD^{o}C days more. Average heat use efficiency was found to be significantly higher in normal sown genotypes for seed (0.95 kg ha^{-1} ºC-days^{-1}) and biological (0.53 kg ha^{-1} ºC-days^{-1}) yield relative to the late sown genotypes for seed (0.50 kg ha^{-1} ºC-days^{-1}) and biological yield (2.71 kg ha^{-1} ºC-days^{-1}). Seed yield under late sown condition had positive and significant correlation with siliquing duration (r= 0.600) and reproductive phase (r= 0.558*) whereas, negative with flowering completion (r= -0.573*) and siliqua initiation (r= -0.519*). Based on the results IAN was the best genotype for delayed sowings.*

Keywords: Heat stress, timely sown, late sown, phenology, seed yield

INTRODUCTION

Mustard (*Brassica juncea* L Czern & Coss) is an important oilseed crop belonging to family *Brassicacae* (*Cruciferae*). Globally, India accounts for 19.8% and 9.8% of the total acreage and production (USDA). Rapeseed mustard is grown under diverse agro ecological situations such as timely/late sown, sole/mixed crop with cereals (wheat, barley, chickpea, lentil etc.). The inter or mixed cropping with wheat and late sowing after rice and cotton exposes Indian mustard to high temperature stress during reproductive stage. Since the beginning of the century, ambient temperature has increased (0.3^{o}C) and is predicted to rise further with climate change (Pandey *et al.,* 2019). Heat stress is detrimental to mustard crop as it suffers decline in photosynthesis (Li *et al.,* 2013). High temperature not only modifies the physiological processes directly but also alters indirectly the developmental pattern of mustard crop leading to differential responses in phenology from one phenophase to another. However, critical temperature thresholds vary among crops, cultivars and phenological stages as reported by Sanchez *et al.,* (2014). Delay in sowing shortens reproductive phase, reduces dry matter accumulation and full genetic yield potential are not realized. Recently, Sharma, (2020) has reported that heat hasten the development of plant specifically, organ size, biomass and yield by shortening seed filling duration leading to a decline in seed weight. The integration of phenological and meteorological climatic data helps to appreciate the direct influence of climate variability on the phenology of crops. Mustard crop requires different growing degree days (GDD) and heat use efficiency (HUE) for different growth and developmental stages and therefore can be used to quantify the effect of temperature and the timing of different biological process. No doubt, the plants have evolved to tolerate or adapt to the stresses and control the decline in productivity of crops but keeping in view the changing climatic conditions, the

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present investigation was planned to study the effect of terminal heat stress on phenology and yield in *B. juncea* and to select the promising genotypes for the breeding programmes.

MATERIALS AND METHODS

A set of fifteen *B. juncea* including advanced lines, introgression lines and quality mustard genotypes were sown during two winter seasons (2017-18 and 2018-19) in the field area of Oilseed Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab at two dates, mid-October as (normal sowing) and end-November as (late sowing. Genotypes were sown in paired rows with row length 5 m at 30 cm row spacing in randomized block design with three replications. Pre-sowing irrigation was given before seeding with urea 90kg acre^{-1} applied in two split doses. Half urea (45 kg acre^{-1}) and single superphosphate (75kg acre^{-1}) applied during preparation of the field. The remaining, second half of urea (45 kg/acre) was applied with first irrigation at 35 days after sowing. Two irrigations were given to mustard crop at 35 and second at 65 days after sowing. All the recommended package and practice were followed to raise healthy crop.

The phenophases in terms of days to flower initiation (first fully developed flower appeared in each plot), 50% flowering (half the plants had fully developed flower), flowering completion (all the plants were in full bloom) were recorded. Dates were also recorded for fruiting behaviour viz., when in each plot at least one flower was converted into siliqua (initiation), half of the plants produced siliquae (50% siliquing) and siliquae appeared in all the plants of a plot (siliquing completion). Days from sowing to different flowering and fruiting dates were counted to compute different phenophases. Physiological maturity was recorded when plants turned yellow, siliquae lemon yellowish and seeds brown to brownish black. Paired rows of each genotype were harvested for biological yield and seeds yield. Yield stability index (YSI) was computed on the basis of seed yield under stressed /late sown and non-stressed condition/ timely sown by using following formula: YSI = Ys_i /Yp_i Where; Yp_i: Seed yield of each genotype under non-stressed/timely sown condition while Ys_i: Seed yield of each genotype under stressed/late sown condition. The meteorological data during two crop seasons was obtained from meteorological observatory of the Department of Climate Change and Agricultural Meteorology, Ludhiana. Agro-meteorological indices were calculated on daily basis of the crop using following formula:

Growing degree days (GDD) $= \left(\frac{T_{max} + T_{min}}{2}\right) - T_b$

T_b= 4.4 ^{o}C (Lal *et al*., 2017)

Heat use efficiency (kg/ha/^{o}C days)

$$= \left(\frac{\text{Aboveground dry matter}}{\text{Accumulated growing degree days (AGDD)}}\right)$$

Analysis of variance (ANOVA) was carried to access the significance of the studied parameters. OPSTAT software was used for correlations analysis and regression in excel worksheet (2010) using data analysis tool

RESULTS AND DISCUSSION

Meteorological parameters during the crop season 2017-18 and 2018-19 depicted the variations recorded during two years of study. Maximum temperature varied from 33.1-34.8 ^{0}C during the first year and 31.1- 35^{0}C during the second year of study coinciding with seed filling stage. During first year, rainfall was 69.4mm and in the second year 172.6mm during the crop season thus water equivalence available to the crop was 189.5 mm and 292.6mm respectively.

Phenology

Days to different phenophases differed significantly within the genotypes and with sowing dates. PBR 422 took 72 days for flower initiation; CM-16 took 81.3 days for 50% flowering and 91 days for flowering completion. Numbers of days for different flowering stages were higher in optimum sowing and decreased with delay in planting for all the genotypes. Significant decline in flowering duration was registered minimum of 9 days in Giriraj trailed by 12.3 days in MCN 09-40. On an average, flowering duration was reduced by 6 days (Table 1). Fruiting behaviour comprising of siliqua initiation increased whereas as 50% and siliquing completion declined significantly when planted late. Siliqua initiation ranged from 70.3 days (JC-210-325 and PBR 357) to 76 days in PBR 422. 50% siliquing was 93.3 days in CM-16

Table 1: Effect of planting date on phenological stages (days) under two crop seasons (average)

Genotypes/ Planting date	Flower initiation		50% flowering		Flowering completion		Flowering duration		Siliqua initiation		50% siliquing		Siliquing completion		Siliquing duration		Reproductive phase		Maturity	
	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
LES 56	59.0	69.7	66.7	80.0	86.0	84.0	27.0	14.3	64.3	75.7	89.7	85.7	105.0	103.0	40.7	27.3	46.0	33.3	126.3	114.3
JC-210-325	50.3	63.0	65.3	73.3	85.7	81.7	35.3	19.0	57.3	70.3	90.0	86.3	112.7	103.7	55.3	33.3	62.3	41.0	118.0	103.0
CJRD-1261	60.0	68.7	72.3	78.7	97.0	83.7	37.0	15.3	66.7	73.0	101.3	87.7	113.0	106.3	46.3	33.3	53.0	38.0	133.3	115.0
RLC-3	59.3	69.3	72.0	79.3	101.3	86.7	42.0	17.3	66.3	75.3	107.0	91.0	116.7	104.7	50.3	29.3	57.3	35.3	132.7	116.7
Giriraj	58.7	66.7	66.0	76.0	85.3	75.7	26.7	9.0	64.7	71.0	86.7	82.3	107.0	104.0	42.3	33.0	48.3	37.3	127.3	118.7
BPR541-4	62.3	65.3	70.3	77.7	85.7	78.0	23.3	12.7	67.7	73.0	89.3	84.7	108.7	105.3	41.0	32.3	46.3	40.0	130.0	115.0
ELM-38	61.0	69.3	73.0	78.0	86.0	85.0	25.0	16.0	67.3	74.0	94.3	85.3	111.3	106.0	44.0	32.0	50.3	37.0	133.0	121.3
CSR 1163	62.3	68.0	70.7	79.7	89.0	85.0	26.7	17.0	67.3	73.3	92.7	89.0	109.7	105.3	42.3	32.0	47.3	37.3	132.3	119.7
CM 21-16	59.0	69.0	71.3	80.7	93.3	88.0	34.3	19.0	65.3	73.7	96.7	90.7	106.3	103.7	41.0	30.0	47.3	34.7	133.3	121.0
CM-16	57.7	70.0	71.7	81.3	95.7	91.3	38.0	21.3	64.0	75.3	101.7	93.3	116.0	102.3	52.0	27.0	58.3	32.3	129.7	117.3
IAN	61.7	67.0	71.3	78.7	89.7	84.7	28.0	17.7	66.7	73.7	97.0	88.0	108.7	104.3	42.0	30.7	47.0	37.3	133.3	115.3
PBR 357	61.0	66.0	70.7	76.0	95.3	83.0	34.3	17.0	67.3	70.3	99.3	84.7	109.3	104.3	42.0	34.0	48.3	38.3	129.3	118.0
PBR 422	65.3	72.0	74.0	80.3	95.3	85.3	30.0	13.3	71.0	76.0	107.3	88.0	113.0	104.7	42.0	28.7	47.7	32.7	138.0	118.3
JT 498	63.3	70.7	71.0	80.3	96.0	85.3	32.7	14.7	69.3	75.0	102.3	89.3	110.3	103.0	41.0	28.0	47.0	32.3	132.7	115.0
MCN 09-40	64.0	69.3	75.3	76.3	99.0	81.7	35.0	12.3	69.7	72.7	105.3	85.3	116.0	105.3	46.3	32.7	52.0	36.0	136.7	119.0
Average	**60.3**	**68.3**	**70.8**	**78.4**	**92.0**	**83.9**	**31.7**	**15.7**	**66.3**	**73.5**	**97.4**	**87.4**	**110.9**	**104.4**	**44.6**	**30.9**	**50.6**	**36.2**	**131.1**	**116.5**
CD (P= 0.05)	E=0.391		E=0.487		E=0.554		E=0.625		E=0.449		E=0.676		E=0.479		E=0.604		E=0.605		E=0.513	
	G=1.069		G=1.334		G=1.517		G=1.713		G=1.231		G=1.852		G=1.312		G=1.655		G=1.658		G=1.405	
	ExG= 1.513		ExG=1.886		ExG= 2.146		ExG=2.422		ExG=1.740		ExG=2.619		ExG=1.855		ExG=2.341		ExG=2.345		Ex G=1.986	

E= Environment, G= Genotypes, E×G= Environment × Genotype , TS-Timely sown, LS- late sown trailed by 91 days in RLC-3. Genotypes CM 21-16, JT 498, LES 56 and JC-210-325 took 103 days, RLC-3, Giriraj, IAN, PBR 357 and PBR 422 took 104 days for siliquing completion. Siliquing duration was comparable in CM-16 and LES 56 (27 days) and of 33.3 days in JC-210-325, CJRD-1261 and Giriraj. Siliqua duration was significantly shortened to 13 days. Conclusively delayed planting shortened the flowering and siliquing duration and resulted in shortening of reproductive phase by 14 days. On an average maturity was hastened by a fortnight. JC-210-325 was early maturing at both the planting dates.

Changes in plant phenology are considered to be the most sensitive and observable indicator of plant responses to climate change. Sharma and Sardana, (2013), Kaur, (2018) and Priya, (2020) reported delayed flowering and siliqua initiation in *B. juncea* while 50% flowering by Kumar *et al.* (2018). Early completion of flowering has also been reported with delayed sowing in *B. juncea* (Kannu Priya, 2019) and in oilseed rape by Ramazani and Kalantari (2019). Flowering duration decreased significantly with delayed planting from 45 (6th October sowing) to 41 days (23rd October sowing) and 35 days (12th November sowing) in *B. juncea*. Further 50% siliquae and siliquing completion was early as reported by Rhythm (2020) under drought and Priya (2020) under terminal heat stress. Earlier reports indicated sudden rise in air temperatures during reproductive stage shortened the seed filling period. Our results in the present investigation of Indian mustard genotypes indicated decline in reproductive phase and early maturity which led to yield penalties. This is in accordance with results of Prasad *et al.,* (2018). Recently Sharma (2020) reported the adverse effect of high temperature on photosynthetic efficiency, translocation and nutrients uptake which ultimately decreased various growth phases causing early/enforced maturity. Late sown mustard crop had shorter reproductive phase as reported earlier by Gupta *et al.* (2017) due to higher temperature. Recently, Prasad *et al.* (2020) revealed the effect of sowing temperature on growth phases and yield of Indian mustard at three dates of sowing D1 (7th November), D2 (17th November) and D3 (27th November) where 7th November sown mustard crop produced higher yield due to optimum thermal and solar light requirements for various processes of plants.

Growing degree days (GDD)

Growing degree days required for Indian mustard to attain different phenophases not only varied within the genotypes but with the sowing dates. Average GDD for initiation of flowering (854 ^{o}C days), 50% flowering (974 ^{o}C days), flowering completion (1232 ^{o}C days) in timely sown crop which decreased with late planting except for 50% flowering (978 ^{o}C days). GDD was higher for the fruiting behaviour of genotypes in the optimum sowing followed by a declining trend under late planting (Table. 2). Average growing degree days were lower (57 ^{o}C days) in late planting. GDD was comparable for flowering completion in PBR 422 and JT 498 and for siliquing completion in BPR541-4, CSR 1163 and MCN 09-40 in late planting. GDD for maturity varied to lesser extent in Giriraj in late planting relative to normal sowing. Growing degree days were commonly adopted to describe different processes of plants biology. This approach implies a direct relation between air temperature and the pace of plant development, higher the temperature, faster the plant develops. Indeed this relation is actually quite far from linear, since plant development does only take place when temperature falls within specific limits called minimum and maximum cardinal temperatures. Inside this range there is the optimum, where plant development is not limited, while between cardinal and optimal limits the pace of plant development is variably reduced (Mariani *et al*, 2013). Our results on GDD at various phenological stages are in conformity to those of Ahatsham *et al.* (2018) where declining trend in GDD with delayed planting dates has been reported. The varietal difference in mustard for facing durations were reported by Lal *et al.* (2020) under shade and open conditions. This shade condition was statistically significant which required more degree days for all the phenological stages as compared to the open condition. The reason could be initial lower thermal efficiency which increased with the duration of the crop.

Table 2: Effect of planting date on GDD and HUE under two crop seasons (average)

Genotypes/ Planting date	Growing degree days (ºC days)														Heat use efficiency (kg ha^{-1} $ºC^{-1}$ days)			
	Flowering behaviour						Fruiting behaviour											
	Flower initiation		50% flowering		Flowering completion		Siliqua initiation		50% siliquing		Siliquing completion		Maturity		Seed yield		Biological yield	
	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
LES 56	842	872	929	995	1153	1066	893	949	1200	1092	1416	1451	1858	1689	0.96	0.39	4.07	2.34
JC-210-325	740	771	912	912	1159	1021	821	878	1202	1103	1578	1473	1683	1451	0.93	0.56	3.90	3.52
CJRD-1261	854	861	990	980	1287	1061	929	902	1356	1130	1584	1522	2007	1700	0.78	0.50	3.74	2.94
RLC-3	844	869	988	987	1362	1107	926	938	1454	1204	1663	1492	1996	1754	0.85	0.43	3.59	2.79
Girriraj	839	834	923	952	1150	949	901	884	1168	1037	1462	1480	1885	1805	1.26	0.59	6.19	3.02
BPR541-4	875	816	966	969	1153	972	940	902	1197	1077	1495	1505	1952	1712	0.85	0.59	4.55	2.92
ELM-38	862	867	1002	972	1156	1082	936	918	1257	1087	1550	1517	2002	1871	1.20	0.46	6.52	2.50
CSR 1163	875	852	970	990	1200	1082	936	905	1234	1158	1517	1504	1990	1826	1.12	0.62	6.83	3.29
CM 21-16	846	867	982	1002	1241	1135	912	915	1249	1198	1444	1473	2007	1853	1.12	0.40	6.09	2.19
CM-16	823	875	985	1024	1277	1209	891	945	1360	1254	1653	1439	1935	1768	0.94	0.30	5.46	1.70
IAN	869	837	982	980	1200	1077	929	915	1292	1135	1495	1485	2007	1718	0.82	0.68	4.93	3.24
PBR 357	862	821	970	952	1274	1053	936	878	1324	1076	1512	1486	1929	1792	0.87	0.56	6.17	2.67
PBR 422	907	892	1015	999	1274	1087	973	952	1459	1136	1584	1492	2131	1798	0.96	0.39	4.41	2.41
JT 498	885	881	973	1005	1281	1087	956	941	1370	1163	1529	1451	1996	1700	0.81	0.56	4.23	3.12
MCN 09-40	891	869	1025	955	1314	1028	960	898	1421	1087	1653	1505	2093	1812	0.85	0.48	4.83	2.09
Average	**854**	**852**	**974**	**978**	**1232**	**1068**	**923**	**915**	**1303**	**1129**	**1542**	**1485**	**1965**	**1750**	**0.95**	**0.50**	**5.03**	**2.71**
	E= 0.332		E=0.445		E=0.418		E=0.489		E=0.598		E=0.614		E=0.531		E=0.184		E=0.369	
CD (p= 0.05)	G=0.908		G=1.215		G=1.144		G=1.341		G=1.637		G=NS		G=1.454		G=0.504		G=0.101	
	ExG=1.284		ExG= NS		ExG=1.618		ExG=1.897		ExG=2.315		ExG=NS		ExG=2.056		ExG=0.713		ExG=0.143	

Heat use efficiency (HUE)

Variations existed within the genotypes for heat use efficiency and also with the sowing dates. Heat use efficiency was higher in Giriraj at seed yield (1.26 kg ha^{-1} ºC-days^{-1}) and in CSR 1163 at biological yield (6.83 kg ha^{-1} ºC-days^{-1}) followed by ELM-38 in timely sown crop whereas in late sown crop it was higher in IAN at seed yield (0.68 kg ha^{-1} ºC- days^{-1}) and in JC-210-325 at biological yield (3.52 kg ha^{-1} ºC-days^{-1}). Average HUE in timely sown condition at seed yield (0.95 kg ha^{-1} ºC-days^{-1}) and biological yield (5.03 kg ha^{-1} ºC-days^{-1}) were significantly greater than the late sown condition (Table 2).HUE depends on biomass production and the production increased with increase of heat use efficiency (Ahatsham *et al*., 2018), a measure of the amount of dry matter produced per unit of thermal unit .Further the decrease in HUE in the stressful environment was dependent on lower biomass production. Similarly decrease in HUE was reported recently by Prasad *et al.* (2020) in Indian mustard which are in accordance with our are findings.

Seed yield and yield stability index

Significant difference existed in the genotypes as indicated by the pooled mean data of two seasons for seed yield in optimum and late plantings (Table 3). ELM-38 (2411 kg ha^{-1}) was the highest yielder followed by Giriraj (2367 kg ha^{-1}) in the timely sown cultivars. Late planted resulted in lower yields where seed filling was hampered by terminal heat stress (>30^{o}C). IAN was the highest yielder when planted late and only suffered yield reduction of <30%. Yield stability index was highest in IAN (0.71) followed by BPR541-4 and PBR 357 (0.60).Heat stress in *Brassica* enhanced plant development and caused flower abortion and poor grain filling with considerable loss in seed yield. Seed yield was reduced with delayed sowing (Priya, 2020) and moisture stress (Rhythm, 2020) in *Brassica juncea.*

Table 3: Effect of planting date on seed yield and yield stability index

Genotypes/ Planting date	Seed yield (kg ha^{-1})		Red (%)	Yield stability index (YSI)
	Timely sown	Late sown		
LES 56	1783±74	664±47	62.7	0.37±0.03
JC-210-325	1558±74	814±89	47.7	0.53±0.08
CJRD-1261	1568±54	854±43	45.5	0.54±0.01
RLC-3	1704±53	756±77	55.7	0.45±0.06
Giriraj	2367±66	1069±24	54.8	0.45±0.02
BPR541-4	1667±66	1007±40	39.6	0.60±0.02
ELM-38	2411±54	856±53	64.5	0.36±0.03
CSR 1163	2226±80	1123±52	49.5	0.50±0.01
CM 21-16	2243±74	746±38	66.8	0.33±0.01
CM-16	1814±25	530±37	70.8	0.29±0.02
IAN	1640±67	1160±59	29.3	0.71±0.07
PBR 357	1687±70	1004±63	40.4	0.60±0.05
PBR 422	2038±61	693±54	66.0	0.34±0.02
JT 498	1626±85	953±93	41.4	0.59±0.05
MCN 09-40	1773±75	868±70	51.1	0.49±0.04
Average	1874±65	873±56		**0.48±0.03**
CD (p= 0.05)	E= 33.7 G= 92.3 E×G= 130.6			

Correlations and regression analysis

Flowering completion and seed yield were negatively associated under timely sown (r= -0.339) and late sown (r= -0.573*) conditions (Table.4). In timely sown condition, siliquing duration was weakly and negatively correlated with seed yield (r= -0.334) but was significantly positive under late sown condition (r= 0.600*). Reproductive phase had positive and significant association (r= 0.558*) in late sown condition. Flowering completion had significant positive correlation with flowering duration both with timely sown (r= 0.796**) and late sown (r= 0.784**) conditions. Siliquing duration had strong positive association with reproductive phase under timely sown (0.995**) and late sown conditions (r= 0.878**). Flowering completion

(R^2= 0.3286), siliquing duration (R^2= 0.3568) and reproductive phase (R^2= 0.3144) had slightly strong relationship in late sown condition (Fig.1). Sharma and Sardana (2015) reported positive association between 50% flowering (0.195) and maturity (0.639**) with seed yield in *Brassicas* under changing climatic conditions.

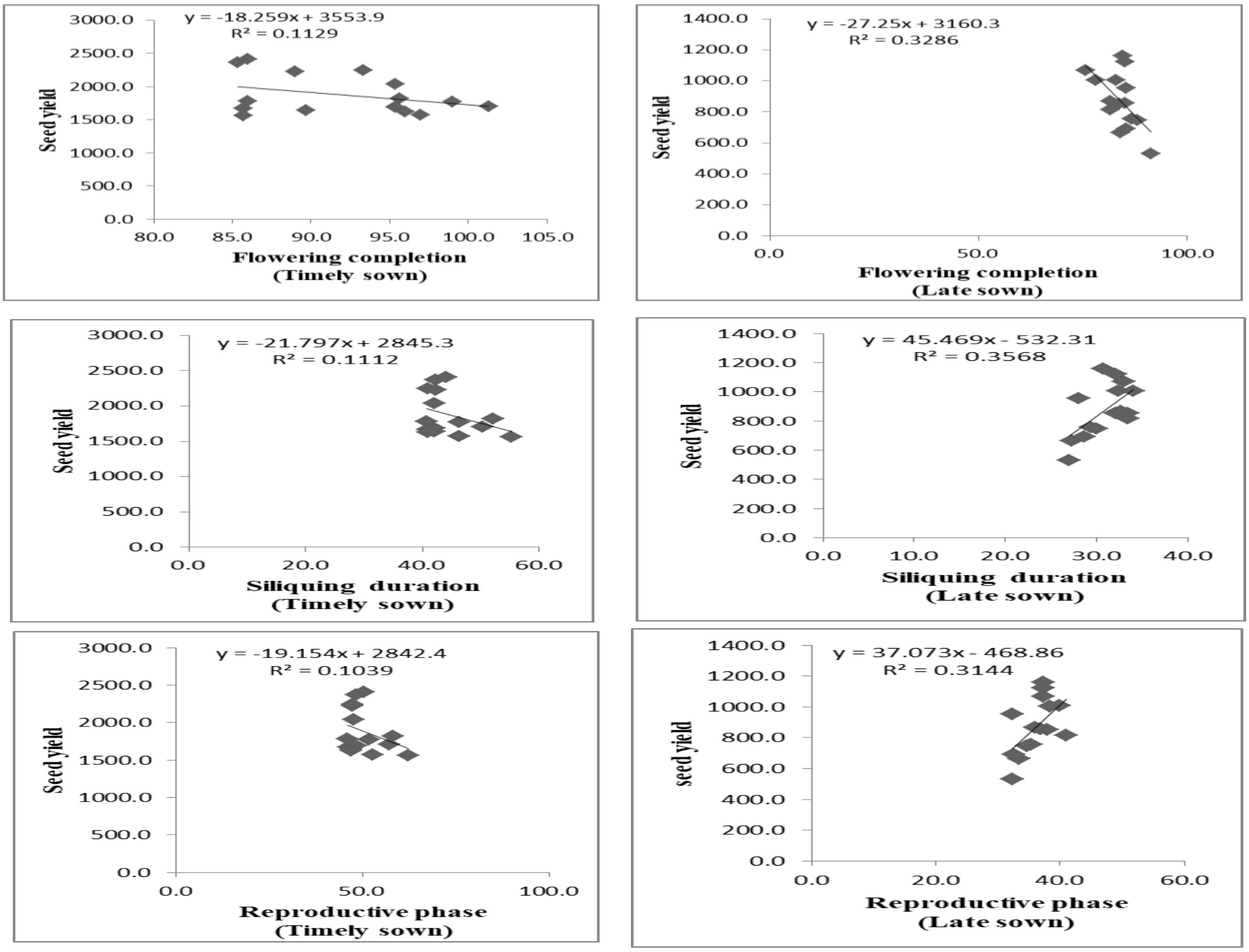

Fig. 1: Relationship of flowering completion, siliquing duration and reproductive phase with seed yield (mean of two years) in *B. juncea*

Table 4: Correlation coefficients of phenological parameters with seed yield under timely (below diagonal) and late sown (above diagonal) conditions

	IF	50% F	100% F	FD	SI	50% S	100% S	SD	RP	M	SY
IF	1	0.790**	0.566*	-0.067	0.835**	0.459	-0.081	-0.690**	-0.896**	0.575*	-0.471
50% F	0.706**	1	0.700**	0.247	0.868**	0.705**	-0.239	-0.794**	-0.790**	0.496*	-0.372
100% F	0.333	0.672**	1	0.784**	0.621**	0.894**	-0.321	-0.644**	-0.620**	0.204	-0.573*
FD	-0.305	0.225	0.796**	1	0.120	0.731**	-0.315	-0.253	-0.069	-0.197	-0.343
SI	0.986**	0.765**	0.438	-0.190	1	0.594*	-0.196	-0.878**	-0.808**	0.301	-0.519*
50% S	0.441	0.789**	0.934**	0.660**	0.538*	1	-0.352	-0.640**	-0.548*	0.081	-0.477
100% S	-0.005	0.535*	0.655**	0.664**	0.090	0.704**	1	0.641**	0.512*	0.259	0.382
SD	-0.686**	-0.107	0.213	0.654**	-0.620**	0.183	0.725**	1	0.878**	-0.101	0.600*
RP	-0.698**	-0.106	0.240	0.689**	-0.619**	0.200	0.720**	0.995**	1	-0.399	0.558*
M	0.875**	0.896**	0.570*	0.015	0.905**	0.673**	0.240	-0.436	-0.434	1	0.068
SY	0.159	0.033	-0.339	-0.44	0.141	-0.277	-0.299	-0.334	-0.324	0.216	1

**Significant at 5%, **Significant at 1%, IF- Initiation of flowering, 50% F- 50% flowering, FC- Flowering completion, FD- Flowering duration, SI- Siliqua initiation, 50% S- 50% siliquing, SC- Siliquing completion, SD- Siliquing duration, RP- Reproductive phase, M- Maturity, SY- Seed yield*

Shortening of flowering and siliquing durations shortened the reproductive phase and resulted in early maturity. Accumulated growing degree days for all phenological parameters were reduced significantly with delayed planting except 50% flowering along with heat use efficiency for seed yield (0.45) and biological yield (2.32) over normal planting. Seed yield in late sown condition had significant positive association with siliquing duration (r=0.600*) and reproductive phase (r=0.558*). Conclusively, BPR541-4, CSR 1163, IAN and PBR 357 performed better under late sown condition and holds promise for late planting in the regions where the rice or cotton harvesting delays the sowing of next rapeseed mustard crop. Phenology and growth of these elite genotypes were least affected, leading to the lesser decline in seed yield as compared to other genotypes in stress condition/ late sown. These identified genotypes can be used in the breeding programmes for developing high yielding genotypes for late sown-high temperature condition, the main task for rapeseed-mustard research.

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