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Research Paper

Effect of elevated temperature on phenology, growth, yield components and seed yield of *Brassica juncea* grown in temperature gradient tunnels (TGT)

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ABSTRACT

Elevated temperature is one of the major production constraints of Indian mustard. The present study was aimed to estimate variations in phenology, yield attributes and seed yield under elevated temperature (ET) in temperature gradient tunnels (TGT) and open field for heat tolerance. Fourteen genotypes consisting of introgression lines and the mustard varieties were sown in TGT and open field for two consecutive *winter* seasons (2017-2019).The phenophases were shortened due to elevated temperature in TGT as compared to control except physiological maturity which was trailed by 17-18 days during both the years. Temperature affect was most severe on siliqua formation and seed filling. Among growth parameters only length of main shoot suffered reduction whereas yield contributing parameters like siliqua on main shoot, siliquae plant^{-1}, seeds siliqua^{-1} and 1000 seed weight along with biomass, seed yield and harvest index suffered significant decline in TGT. Average temperature had positive correlation with all phenological parameters except flowering completion, growth parameters except number of primary and secondary branches while yield attributes only with 1000 seed weight, biomass and seed yield under TGT. Interestingly, number of primary branches had significant negative correlation with average temperature under both control (r=-0.59*) and TGT (-0.61*). Phenological traits had strong relationship with seed yield under TGT. However, seed yield had strong relationship with growth parameters, yield attributes under control except for number of primary branches. Biomass had strong relationship with seed yield under both TGT (R^2= 0.51) and control (R^2= 0.43). Two years testing revealed introgression lines (JA24 and JA53) and varieties (JD6 and Giriraj) tolerant to heat stress.

Keywords: Elevated temperature, Indian mustard, temperature gradient tunnel, phenophases and yield attributes

Global temperature is rising at an unprecedented rate. IPCC sixth assessment report predicted a rise of 1.5 °C in temperature within next two decades (IPCC, 2021).This change is expected to increase the frequency and intensity of abiotic stress that injure plants, posing a severe threat to global crop productivity and food security. Plants being sessile organisms are continuously challenged by a broad range of abiotic stresses such as high temperature, drought, salinity *etc*. hindering yield and quality of crops (Sodani *et al.,* 2017). High temperature is a prominent abiotic stress that is proving to be the most restricting component for normal plant growth and development.Several characteristics that govern responses of plant to high temperature are supposed to be environmental factors such as plant type, time span of stress and also strength of stress (Prasad *et al.,* 2017). Impact of high temperature at early stage arrests seed germination and delays emergence (Deng *et al.,* 2015). High temperature at vegetative stage impair light perception, carbon metabolism, photosynthetic pigments and translocation of solutes (Asseng *et al.,* 2015) whereas at reproductive stage results in inactivation of defense system, production of ROS and imbalance of mineral nutrition (Zhang *et al.,* 2016). Rapeseed- mustard is an imperative oilseed crop of India which is grown for its exceptional yield and relative tolerance to stress conditions for example heat (Chugh *et al.,* 2022), drought (Rhythm *et al.,* 2022), salinity (Kannupriya *et al.,* 2021) and low light stress (Kaur and Sharma*,* 2021).

In Indian subcontinent rapeseed-mustard holds 2nd position in production, after soybean, but ranks first in terms of

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oil yield among all oilseed crops. Production of mustard in India is estimated to be 11.75 MT (Indiastat, 2021-2022) whereas the area under production and productivity is estimated to be 6.70 mha and 1524 Kg ha^{-1} (Indiastat, 2020-2021).It is primarily grown in North West part of India and Haryana, Uttar Pradesh and Rajasthan are the major producing states. Mostly it is grown for edible oils, fodder, vegetables and condiments. Due to late sowing after rice and cotton as well as inter/ mixed cropping with wheat exposes the mustard crop to heat stress during reproductive phase which declines, duration and rate of metabolic processes leading to yield reduction (Sharma, 2020). Since temperature is major determinant of plant phenology, heat stress cause stunted growth and morphological alterations, depending on the time of exposure. At early seedling and seed filling stage rapeseed-mustard is highly susceptible to heat stress (Sharma and Sardana, 2013, Sharma, 2020).

Under late planting and changing climate conditions, elevated temperature is predicted to increase yield losses. The crop damage taking place due to uncertain climatic conditions needs crucial improvement in approaches for advancement in food availability and crop production. Plant responses that lead to the tolerance against heat stress are center of attraction for plant scientists. Heat tolerant varieties are need of time for crop sustainability therefore fourteen germplasm lines along with varieties were evaluated under controlled and elevated temperature in TGT.

MATERIALS AND METHODS

Study location

The present investigation was conducted in the temperature gradient tunnels (TGT) located in the field area of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University during 2017-18 and 2018-19. Ludhiana region characterized by semi-arid, sub-tropical type of climate with hot and dry summer followed by hot and humid period and cold winter period. It is situated at 30°56′ N latitude and 75°48′ E longitude at an altitude of 247 meters above the sea level.

Crop and plot details

Fourteen mustard cultivars comprising introgression lines (JT12, JT128, JT593, JT575, JT151, JA53, JT9, JA24 and JT77), released varieties (Giriraj, JD6, PBR378, PHR126) and BPR541-4 registered line for heat tolerance were sown in paired rows with row to row spacing of 30 cm and plant to plant spacing of 1.5 cm in open field (control) and in temperature gradient tunnel (TGT). The cultivars were sown in randomized block design with three replications and the sowing was done in mid-November 2017 and 2018. Standard agronomic practices of irrigation and fertilizers were followed to raise healthy crop stand.

Temperature gradient tunnel (TGT) structure

The temperature gradient tunnel (TGT) was made up of galvanized iron pipes, covered with polythene sheets (500 µm thickness) with dimensions 30 m in length, 5 m in breadth and 3 m in height. The temperature maintained in tunnels was 3 to 4 °C higher than the normal ambient condition. The genotypes grown in TGT germinated but were yellow, lanky seedlings, therefore the tunnels were opened for light availability to overcome the problem. The meteorological data within the temperature gradient tunnel was monitored with a set of five installed temperature and relative humidity sensors along with one radiation sensor. One set of these sensor were installed outside the temperature gradient tunnel to monitor the ambient air temperature and relative humidity data. The data was automatically recorded by the data logger (Delta T Devices) at five minutes interval and logged at half an hour interval (Fig 1).

Fig 1: Mustard crop at flowering stage in TGT and control

Elevated temperature detail

Data was downloaded at the end of the crop season and was critically analyzed during different crop phases with minimum, maximum and average temperature recorded during 2017-18 and 2018-19. During sowing time temperature was 1 to 1.5 °C higher in control whereas in the month of December the weekly as well as monthly maximum temperature was ۳ °C higher in TGT with similar variation in average temperature. However, the minimum temperature in control was lower with respect to TGT. During the seed filling stage commencing in the month of March average temperature was 5 to 7° C higher in TGT till the harvesting of the crop in first fort night of April. For precision average temperature variations during the different crop growth phases have been tabulated in Table 1. Starting from emergence till maturity the crop faced higher temperature in the TGT in comparison with the control.

Crop observations

The phenological stages (days to flower initiation, flowering completion, flowering duration, siliqua initiation, siliquae completion, siliquing duration, reproductive phase and physiological maturity) were recorded. The growth parameters included plant height, length of main raceme and number of primary and secondary branches plant^{-1} and yield attributes (siliquae on main shoot, siliquae plant^{-1}, seeds siliqua^{-1} and 1000 seed weight), yield (biological yield and seed yield) along with harvest index were recorded at maturity.

Table 1: Variation in average temperature recorded in control and TGT during two crop season (2017-19)

Phases	Control			TGT		
	DAS	2017-18 Average temperature (°C)	2018-19 Average temperature (°C)	DAS	2017-18 Average temperature (°C)	2018-19 Average temperature(°C)
Emergence	5	20.0	18.9	6	19.4	18.1
Seedling establishment	15	20.8	18.7	16	21.5	19.7
Vegetative	57	18.5	14.8	56	21.4	17.3
Flowering	79	15.3	12.3	70	20.3	18.6
Siliquing	111	17.8	13.9	95	23.2	19.6
Maturity	136	18.6	16.0	154	24.7	21.5

Table 2: Phenophases of Indian mustard as influenced by elevated temperature (pooled mean of *rabi* 2017-18 and 2018-19)

Treatments	Flowering			Siliquing			Reproductive phase	Days to maturity
	Initiation	Completion	Duration	Initiation	Completion	Duration		
Environment								
Control	60.5	79.2	18.8	67.4	110.6	43.1	50.1	136.5
TGT	49.5	64.2	14.6	56.5	95.0	38.1	45.4	154.1
CD (*P*=0.05)	0.20	0.19	0.20	0.18	0.18	0.21	0.19	0.20
Genotypes								
JT12	50.5	70.0	19.4	58.5	99.6	41.1	48.9	146.9
JT128	53.5	74.0	20.5	60.3	110.8	40.3	47.2	146.1
JT593	56.5	72.5	15.9	64.0	103.7	39.8	47.0	144.8
JD6	54.8	70.5	15.6	60.9	102.4	41.4	47.5	145.4
JT575	53.2	69.6	16.6	62.3	104.2	41.6	50.9	142.8
JT151	56.4	71.1	14.6	62.4	101.5	38.9	45.0	145.0
PBR378	55.1	72.0	16.8	62.5	103.0	40.3	47.7	143.5
JA53	56.3	73.0	16.6	60.9	104.6	43.8	48.4	145.0
JT9	56.8	70.1	13.5	62.7	105.2	42.3	48.4	145.9
Giriraj	54.2	72.9	18.7	62.3	101.4	39.0	47.1	145.2
JA24	55.8	71.1	15.4	62.8	103.5	40.4	47.9	145.8
JT77	54.3	72.6	18.3	62.9	102.3	39.3	47.9	146.8
BPR541-4	57.5	73.0	15.3	62.8	104.4	41.5	46.8	146.0
PHR126	55.3	70.9	14.9	62.5	101.9	39.0	45.8	146.5
CD (*P*=0.05)	0.52	0.53	0.51	0.48	0.47	0.57	0.50	0.53
CD (E × G) at (*P*=0.05)	0.73	0.75	0.73	0.68	0.67	0.82	0.71	0.75

Table 3: Pearson's correlation coefficients of phenological parameters with average temperature (pooled mean) under control (below the diagonal) and TGT (above the diagonal)

	FI	FC	FD	SI	SC	SD	RP	DM	AVG
FI	1	0.50	0.09	0.41	0.56*	0.26	-0.17	-0.21	0.28
FC	0.24	1	0.29	-0.05	0.10	0.14	-0.37	-0.13	-0.15
FD	-0.85**	0.31	1	0.18	-0.34	-0.45	-0.26	-0.44	0.13
SI	0.92**	0.42	-0.68**	1	0.29	-0.40	0.10	-0.32	0.20
SC	0.60*	0.28	-0.44	0.62*	1	0.76**	0.69**	0.20	0.15
SD	-0.33	-0.15	0.25	-0.39	0.47	1	0.59*	0.41	0.11
RP	-0.62*	-0.02	0.60*	-0.51	0.25	0.86**	1	0.32	0.21
DM	-0.17	0.17	0.25	-0.16	-0.29	-0.15	-0.17	1	0.16
AVG	0.53	0.32	-0.35	0.64*	0.20	-0.49	-0.46	0.22	1

*Significant at 5%, **Significant at 1%, FI- Initiation of flowering, FC- Flowering completion, FD- Flowering duration, SI- Siliqua initiation, SC- Siliquing completion, SD- Siliquing duration, RP- Reproductive phase, DM- days to maturity, AVG- average temperature

Statistical analysis

To test the significance of treatments and the relative performance of genotypes the data recorded in field and TGT was analysed statistically using construction plant competence scheme (CPCS1 2008) computer programme in factorial randomized block design. Online statistical software OPSTAT (14 139 232 166) was used to analyze pearson's correlation between phenological, yield attributes, seed yield (independent variable) with average temperature (two years pooled mean) (dependent variable). In excel worksheet (2007) version (12.04518.1014) regression analysis between studied traits and seed yield was calculated using data analysis tool.

RESULT AND DISCUSSION

Phenological response

The phenological calendar of Indian mustard cultivars inside TGT and control for both years is presented in Table 2. In consecutive years 2017-2018 and 2018-2019 all the phenological events were early except physiological maturity in TGT grown mustard as compared to controlled conditions and the interactions between environment and genotypes were also significant. During both the years, initiation of flowering was early by 11 days and siliqua by 10-12 days in TGT sown genotypes. Flowering and siliquing completion was earlier by 15-16 days each thus resulting in shortening flowering and siliquing duration by 4-6 days.

Mean reproductive phase was shorter by 4-5 days thus the crop duration of all Indian mustard genotypes decreased with increase in temperature in TGT. Overall, the genotypic mean indicates 142±1.5 days in JT575 over the two years while 147.5 days maturity in first year by JT77 and early maturity by one day in the second year. JD6 took almost 145 days to mature in 2017-18 and 2018-19. Average temperature in TGT of entire crop season during 2018-2019 was higher by 4 °C than 2017-2018 resulting in late maturity by one day in 2019 (155 days) as compared to 2018 (154 days). Among genotypes studied in two years, window of crop maturity was least affected in genotype JT128 and overall, JD6 had shorter flowering and siliquing durations along with the reproductive phase under both the environments indicating better adaptability under high temperature conditions. Inappropriate dry matter translocation or senescence related metabolic impairment or both may lead to delayed maturity according to Priya (2020). Recently, Shivran *et al.*, (2022) reported that phenophases of mustard like days to 50% flowering, initiation of siliqua *etc* were shortened except days to maturity due to high temperature. Further poor performance of crop due to delayed sowing resulted in shorter growing time which delays maturity and results in yield losses. Correlation (Table 3) analysis revealed that siliquae initiation (r= 0.64*) had significant positive association with average temperature under controlled conditions. Regression analysis showed siliquing completion (R^2= 0.41), siliquing duration (R^2= 0.20) and reproductive phase (R^2= 0.31) had strong relationship with seed yield under TGT as compared to controlled conditions. Our results are consistent with findings of Bazzaz *et al.*, (2020) and Rameeh, (2012) who reported that high temperature due to late sowing strongly affected flowering duration and maturity of mustard which ultimately affects the seed yield.

Growth parameters

Plant height

Comparison among both the treatments in two years of study indicated 11-12% more plant height i.e. taller in TGT sown cultivars. The interactions between environment and genotypes (E×G) were significant with respect to plant height (Table 4). The comparison among the genotypes for both the years showed that Giriraj recorded minimum (151-153 cm), whereas JT151 maximum (186-193 cm) plant height under TGT. Overall, during the years minimal increase was in Giriraj. The correlation analysis showed that the TGT cultivars recorded increased plant height due to positive association between the average temperature and plant height in both the environments (Table 5). Restricted sunlight and relatively higher temperature inside the tunnel lead to increased plant height or taller plants with hollow stems. According to Chen *et al.,* (2020) plant height increased due to heat stress at 32/ 22° C and 35/ 25° C in canola. Our results are consistent with the findings of No *et al.,* (2021) in soybean and Kaur *et al.,* (2019) in rice where

Table 4: Growth parameters, yield attributes and seed yield of Indian mustard as influenced by elevated temperature (pooled mean of *rabi* 2017-18 and 2018-19)

Treatments	Plant height (cm)	Length of main shoot (cm)	Primary branches plant^{-1}	Secondary branches plant^{-1}	Siliquae on main shoot	Total siliquae plant^{-1}	Seeds siliqua^{-1}	1000 seed weight (g)	Biomass (q ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
Environment											
Control	155.2	79.3	4.2	11.3	43.1	259.3	15.1	5.0	146	3028	22.8
TGT	173.0	72.0	4.9	13.6	39.2	219.8	12.8	4.3	81	1727	19.0
CD (*P*=0.05)	0.24	0.23	0.19	0.24	0.20	0.22	0.32	0.33	10.50	34.00	0.57
Genotypes											
JT12	163.5	75.2	4.4	12.5	43.0	230.8	14.5	5.0	108	2172	19.9
JT128	159.5	63.3	5.7	13.1	35.5	230.0	12.7	4.6	116	2072	18.1
JT593	168.3	81.8	5.5	15.8	40.8	269.8	13.9	4.4	112	2453	21.2
JD6	166.3	72.1	4.9	14.2	41.5	263.1	14.1	5.1	96	2201	23.0
JT575	149.5	72.9	5.4	15.4	42.4	307.8	14.4	3.7	120	2654	21.4
JT151	174.8	74.4	5.0	11.0	40.7	233.3	15.4	3.8	128	2374	19.5
PBR378	168.3	78.5	4.8	10.9	45.1	224.6	12.7	4.5	117	2161	21.4
JA53	164.2	80.1	4.4	13.3	43.0	236.4	13.5	5.1	112	3006	25.0
JT9	163.0	75.9	5.0	15.0	43.2	280.7	13.4	5.2	103	2130	19.1
Giriraj	150.7	79.9	3.1	7.0	44.4	188.0	13.4	5.9	120	2328	19.2
JA24	174.8	83.6	3.6	11.0	43.3	212.8	14.0	5.6	120	2567	21.6
JT77	160.4	68.7	4.2	13.0	32.8	254.9	14.5	4.2	112	2930	26.4
BPR541-4	169.8	76.8	3.4	10.3	38.8	182.2	12.5	5.4	107	2091	19.2
PHR126	160.9	75.5	4.5	11.1	44.2	251.0	14.4	4.8	114	2148	17.5
CD (*P*=0.05)	0.66	0.62	0.50	0.64	0.54	0.58	1.24	1.11	27.80	90.00	1.52
CD (E×G) at (*P*=0.05)	0.93	0.88	0.71	0.91	0.77	0.82	NS	NS	39.40	127.30	2.15

plant height increased due to temperature stress.

Length of main shoot

Length of main raceme was negatively influenced by high temperature during both years (Table 4) and was reduced by 10% in TGT over controlled condition. Environment × Genotype interactions were significant for main raceme length. Maximum reduction in main shoot length was recorded in JT593 (31%) whereas minimum reduction (≤ 2%) in JT128, JT151, BPR541-4. Our study of correlation (Table 5) revealed positive association of main shoot length with average temperature under both controlled (r= 0.18) and TGT conditions (r= 0.15). In *B.juncea* main raceme length decreased due to high temperature caused by late planting conditions (Sharma and Sardana, 2013) and due to salinity stress (Kainat and Sajad, 2021 and Kannupriya *et al.,* 2021).

Number of primary and secondary branches plant^{-1}

The two year analyzed data revealed that primary and secondary branches plant^{-1} were higher in TGT as compared to the open field conditions (Table 4). Increase in number of primary branches was 17-19% and secondary branches 20-22% under TGT for both the crop seasons. However, the interactions between environment and genotypes (E×G) were significant for both the primary and secondary branch number during first year but non-significant during the second year. The number of primary branches was comparable in JA24 followed by minimal decrease in JT77 and JT12. Interestingly, secondary branch number was not much affected in JT575 under both the studied situations and years with maximum increase of ≥ 40% in JT12. Average temperature had significant negative correlation with primary branches under both control (r= -0.59*) and TGT (r=-0.61*) (Table 5). Seed yield had strong relationship with primary branches under TGT (R^2=0.36) as compared to control (R^2=0.18) (Table 6). Our results have parallism with Macova *et al.,* (2021) who reported increased number of branches in *B. napus* with temperature stress.

Yield components

Yield components mainly seeds siliqua^{-1}, siliqua on main shoot, total siliquae plant^{-1}, 1000 seed weight recorded significant decline with high temperature for both 2017-2018 and 2018-2019 (Table 4). In TGT, seeds siliqua^{-1} were reduced by 12 - 14%, siliqua on main shoot by 9 - 11%, total siliquae plant^{-1} by 14 - 16% and 1000 seed weight by 10 - 12% during both the years as compared to open field environment. Interactions between environment and genotype (E×G) were significant for siliqua on main shoot and siliquae plant^{-1}

Table 5: Pearson's correlation coefficients of growth and yield parameters with average temperature (pooled mean) under control (below the diagonal) and TGT (above the diagonal)

	PH	MSL	PB	SB	SMS	TS	S/S	SW	SY	BY	HI	AVG
PH	1	0.20	0.21	0.17	-0.07	0.20	0.22	-0.42	-0.11	0.07	-0.07	0.11
MSL	0.21	1	-0.59*	-0.49	0.71**	-0.35	0.24	0.49	0.40	0.61*	-0.10	0.15
PB	-0.31	-0.29	1	0.69**	-0.21	0.66*	-0.07	-0.61*	-0.54*	-0.46	-0.13	-0.61*
SB	-0.28	-0.07	0.77**	1	-0.29	0.84**	-0.05	-0.40	-0.15	-0.41	0.21	-0.50
SMS	-0.26	0.51	-0.14	-0.06	1	-0.12	0.17	0.32	0.12	0.21	-0.24	-0.17
TS	-0.50	-0.12	0.69**	0.77**	-0.13	1	0.20	-0.45	-0.22	-0.30	0.03	-0.38
S/S	-0.06	-0.10	0.18	0.10	-0.06	0.33	1	-0.20	0.20	0.26	0.30	-0.13
SW	0.39	0.26	-0.68**	-0.49	0.29	-0.72**	-0.53	1	0.37	0.60*	-0.14	0.19
SY	-0.29	-0.02	0.40	0.49	-0.26	0.74**	0.32	-0.74**	1	0.44	0.71**	0.27
BY	-0.20	-0.23	0.42	-0.03	-0.32	0.34	0.17	-0.72**	0.52	1	0.03	0.20
HI	0.15	0.16	-0.03	0.40	-0.20	0.30	-0.28	-0.03	0.53	-0.09	1	-0.14
AVG	0.14	0.18	-0.59*	-0.31	-0.10	-0.35	0.22	0.19	-0.14	-0.18	0.08	1

*Significant at 5%, **Significant at 1% PH- Plant height, MSL- Main shoot length, PB- Primary branches, SB- Secondary branches, SMS- Siliquae on main raceme, TS- total siliquae/plant, S/S- seeds per siliquae, S W- 1000 seed weight, BY- Biological yield, HI- Harvest index, AVG- average temperature

Table 6: Relationship of growth parameter and yield attributes with seed yield

Regression	Control		TGT	
	y= mx+c	R^2	y= mx+c	R^2
Primary branch plant^{-1}	256.7x+1897	0.18	-189.0x+2650	0.36
Total siliquae plant^{-1}	8.332x+835.4	0.61	-2113x+2163	0.08
1000 seed weight	-443.0x+5248	0.66	212.1x+734.6	0.17
Biomass	13.76x+1042	0.44	11.31x+782.7	0.32
Harvest index	84.41x+1139	0.30	16.41x+1387	0.01

while non-significant for seeds siliqua^{-1} and 1000 seed weight. Overall for both the years, JD6 and JT9 suffered minimal reduction for the studied yield components except 1000 seed weight whereas Giriraj suffered minimal reduction in total siliquae plant^{-1} and also 1000 seed weight except for seeds siliqua^{-1}. Total siliqua plant^{-1} had negative association with average temperature under both control (r= -0.35) and TGT (r= -0.38) whereas seeds siliqua^{-1} had positive association with average temperature under control (r= 0.22) but negative under TGT (r= -0.13) (Table 5).Primary branches (r=0.66**) and secondary branches (r= 0.84**) showed significant positive association with total siliquae plant $^{-1}$ in the TGT grown cultivars. Similarly, total siliquae plant^{-1} and 1000 seed weight had strong relationship with seed yield under controlled conditions over TGT (Table 6). Number of siliqua on the main stem is potential measure of tolerance to heat stress in canola where early heat stress reduced siliqua on main stem and late heat stress reduced number of siliqua on branches (Chen *et al.,* 2020). Our results are in consistence with results of Chen *et al.*, (2020), Ahmad *et al.*, (2021), where reduction in total siliquae plant^{-1}, seed weight and seeds siliqua^{-1} in *Brassica* species under temperature stress have been reported. Earlier findings of Sharma and Sardana, (2013) have also reported the impact of terminal heat stress on the decreased total number of siliquae in *Brassica* species.

Biomass yield

Increased temperature in tunnel caused significant decrease in biological yield in both the years (Table 4). Biomass was 46-47% reduced in TGT as compared to control however, interactions (E×G) were significant for biomass. Elevated temperature during both the years reduced maximum biomass in PBR378 (64-65%) and minimum reduction was in JA24 (2-3%).

Biomass had positive correlation with average temperature under TGT conditions (r=0.20) and negative under controlled conditions (r=-0.18) (Table 5).Seed yield had strong relationship with biomass under both control (R^2=0.44) and TGT (R^2=0.32) conditions as marked out by regression analysis (Table 6). Earlier studies had also revealed reduced biological yield of Indian mustard in response to high temperature (Sharma and Sardana, 2013; Priya, 2020; Sharma, 2020).

Seed yield

Seed yield was significantly reduced in TGT for both years as compared to controlled conditions (Table 4). Seed yield reduction was 41.6% (2017-2018) and 43.8% (2018-2019) in TGT. Interactions between environment and genotypes were significant for seed yield. Overall during both years, maximum reduction in seed yield was recorded in JT575 (59%) whereas JD6, JA53, Giriraj, JA24 and BPR541-4 were consistently tolerant on the basis of ≤ 35% yield reduction. Similar results on seed yield reduction have been reported in *Brassica species* (Priya, 2020; Kheir *et al.*, 2021; Chen *et al.*, 2020; Wu *et al.*, 2020) and in green gram (Singh *et al.,* 2021).

Harvest index

Elevated temperature during the years significantly reduced harvest index in TGT (Table 4). HI was reduced by 7-16% in TGT over control during two years of study. Interactions were significant between genotype and environment for HI. Among two years tested genotypes JT128 and JT12 had minimal decline in harvest index. Positive association existed between HI and average temperature under control but the correlation was negative under TGT (Table 5). Strong relationship of HI with seed yield (Table 6) was found in control (R^2=0.30) only. Similar results were reported by Chen *et al.*, (2020) in *B.napus* with high temperature.

CONCLUSION

Mustard genotypes faced relatively high temperature and lesser solar radiations which shortened the phenophases along with the reproductive phase except maturity hindering the dry matter translocation, senescence-causing metabolic impairement or both the processes which delayed the maturity. Plants were taller with more number of branches and hollow stems in TGT grown genotypes. Seed yield was reduced due to decline in yield attributes however, the response was genotype specific. Average temperature had significant positive association with siliqua initiation under control only whereas significant negative association with primary branch number under both TGT and control. Strong relationship of seed yield with siliqua completion, reproductive phase and primary branches plant^{-1} existed under TGT whereas total siliquae plant^{-1}, 1000 seed weight had strong relationship with seed yield under control. Interestingly, biological yield had strong relationship with seed yield in TGT and control. Rigorous testing of the genotypes over the years revealed two introgression lines (JA24 and JA53) and two varieties (JD6 and Giriraj) tolerant to elevated temperature conditions.

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