International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(6): 1839-1841

Received: 13-09-2019
Accepted: 15-10-2019

Deven Verma
Division of Vegetable Crops, ICAR-IIHR, Bengaluru, Karnataka, India

Aghora TS
Division of Vegetable Crops, ICAR-IIHR, Bengaluru, Karnataka, India

Laxman RH
Division of Plant Physiology and Biochemistry, ICAR-IIHR, Bengaluru, Karnataka, India

Dhananjaya MV
Division of Genetics and Plant Breeding, ICAR-IIHR, Bengaluru, Karnataka, India

Corresponding Author:
Deven Verma
Division of Vegetable Crops, ICAR-IIHR, Bengaluru, Karnataka, India

Effect of heat stress on growth indices in garden pea (*Pisum sativum* var. *hortense*)

Deven Verma, Aghora TS, Laxman RH and Dhananjaya MV

Abstract
Heat stress is a serious threat to crop production worldwide, due to global warming. High temperature adversely affects the crop growth, development and economic yield. It causes reduction in shoot dry mass, growth and net assimilation rates. Garden pea being a cool season crop is affected by high temperature as compared to other summer season crops. With an objective to find out the effect of heat stress on growth indices like CGR, NAR, LAI, etc. the study was conducted. The results depicted that heat stress affects the growth indices by reducing the biomass accumulation; however, the rate of biomass accumulation is related to tolerance level of the genotype to heat stress. The heat tolerant genotypes performed better in natural heat stress conditions as compared to susceptible genotypes.

Keywords: CGR, NAR, LAI, heat stress, garden pea

Introduction
Heat stress is defined as the rise in temperature above the optimum level for a period of time sufficient to cause irreversible damage to plant growth and development. It is a complex function of intensity, duration of exposure and rate of increase (Wahid *et al.*, 2007) [12]. Heat stress is a serious threat to crop production worldwide (Hall, 2001) [4]. High temperature stress disrupts the biochemical reactions fundamental for normal cell function in plants and it adversely affects the crop growth, development and economic yield. It causes reduction in shoot dry mass, growth and net assimilation rates (Wahid *et al*., 2007) [12]. It causes an array of morpho-anatomical, physiological and biochemical changes by affecting photosynthesis, respiration, water relations and membrane stability (Prerna *et al.*, 2013; Wahid *et al.*, 2007) [9, 12]. Heat stress during reproductive stage is more harmful than during the vegetative stage (Cossani & Reynolds, 2012) [2]. Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperature (Wahid *et al.*, 2007) [12]. In response to the high temperature stress, plants manifest different mechanisms for surviving under elevated temperatures, including long-term evolutionary phenological and morphological adaptations and short-term avoidance or acclimation mechanisms such as changing leaf orientation, transpirational cooling, or alteration of membrane lipid compositions. In many crop plants, early maturation is closely correlated with smaller yield under high temperatures, which may be attributed to the engagement of an escape mechanism (Adams *et al*., 2001) [1]. Changing leaf orientation, leaf rolling and transpirational cooling are related to avoidance mechanism whereas, osmo-protectants, cell membrane stability, expression of stress proteins and signaling and transcriptional control are tolerance mechanism for heat tolerance (Hasanuzzaman *et al.*, 2013) [5].

Material and Methods
The experiment was carried out at Vegetable Research Block (Block VIII) under Division of Vegetable Crops, ICAR- Indian Institute of Horticultural Research, Bengaluru in 2016. The average maximum temperature recorded during the crop duration was 35.3 °C, with a range of 39-27 °C, whereas, the minimum temperature observed during the season was ranged between 26 and 18 °C (with an average of 22.4 °C).
The experimental material, which was grown under field conditions in summer season, was collected from Division of Vegetable Crops, ICAR-Indian Institute of Horticultural Research, Bengaluru. Eight garden pea germplasm lines, which differed for their response to heat tolerance, were studied for growth indices associated with high temperature tolerance under field conditions.

For calculating different growth indices in the eight genotypes, fifteen uniform plants per genotype were identified and tagged. Above ground plant parts were collected from five tagged plants at 50 days after sowing followed by 65 days after sowing. The leaves were separated from the shoot and the area was recorded (to calculate leaf area index) after which everything was dried in a hot air oven at 70 °C and their dry weight was recorded to calculate the following indices using the standard formulas as mentioned below in Table 1.

Table 1: Growth indices with their respective formulae

Sr. no.	Growth Index	Formula	Reference
1.	Leaf Area Index	$LAI = \frac{Total\ leaf\ area\ of\ a\ plant}{Ground\ area\ occupied\ by\ the\ plant}$	Williams, 1946
2.	Leaf Area Ratio	$LAR = \frac{Leaf\ area\ per\ plant}{Plant\ dry\ weight}$	Radford, 1967
3.	Specific Leaf Area	$SLA = \frac{Leaf\ area\ per\ plant}{Leaf\ dry\ weight}$	Kvet *et al.*, 1971
4.	Net Assimilation Rate	$NAR = \left\{\frac{W_2 - W_1}{t_2 - t_1}\right\} \times \left\{\frac{log_e L_2 - log_e L_1}{L_2 - L_1}\right\}$	Williams, 1946
5.	Relative Growth Rate	$RGR = \left\{\frac{log_e W_2 - log_e W_1}{t_2 - t_1}\right\}$	Williams, 1946
6.	Crop Growth Rate	$CGR = \left\{\frac{W_2 - W_1}{\rho(t_2 - t_1)}\right\}$	Watson, 1956

Results and Discussion

The data presented in Table 2 demonstrate that the maximum leaf area index (2.81), specific leaf area (365.57) and leaf area ratio (166.48) after fifty days of sowing were found in Arka Tapas, whereas they were recorded minimum in IIHR 544 (1.03), Arka Pramod (153.62) and IIHR 544 (52.01), respectively. Sixty five days after sowing the highest leaf area index was found in the line Arka Pramod (1.68), whereas specific leaf area and leaf area ratio were recorded in Arka Chaitra (166.82 and 61.23, respectively). The minimum LAI (0.73) and LAR (22.47) were observed in IIHR 544, whereas specific leaf area was noticed in Arka Ajit (86.55). The highest NAR, RGR and CGR were recorded in IIHR 544 (0.00134), Arka Chaitra (0.0448) and Arka Uttam (0.000975), whereas lowest were observed in Arka Sampoorna (0.00007, 0.0026 and 0.000015, respectively).

Table 2: Effect of high temperature stress on different growth indices in eight selected lines grown in summer season of the year 2016

Lines	Leaf area index (LAI)		Specific leaf area (SLA)		Leaf area ratio (LAR)		NAR	RGR	CGR
	50 DAS	65 DAS	50 DAS	65 DAS	50 DAS	65 DAS			
Arka Chaitra (T)	1.09	0.88	184.91	166.82	85.01	61.23	0.00100	0.0448	0.000927
Arka Tapas (T)	2.81	1.26	365.57	110.37	166.48	40.04	0.00051	0.0375	0.000905
Arka Uttam (T)	1.35	0.91	220.98	123.12	93.26	36.46	0.00092	0.0389	0.000975
IIHR 544 (T)	1.03	0.73	250.86	133.59	52.01	22.47	0.00134	0.0391	0.000958
Arka Ajit (CC)	1.42	0.85	248.72	86.55	102.23	38.59	0.00048	0.0313	0.000515
Arka Pramod (S)	2.17	1.68	153.62	118.44	71.44	44.73	0.00023	0.0125	0.000497
Arka Priya(S)	1.47	1.38	217.49	114.08	76.45	37.90	0.00025	0.0112	0.000244
Arka Sampoorna (S)	1.64	0.89	157.64	100.03	67.85	32.69	0.00007	0.0026	0.000015
Mean ± SEm	1.75 ± 0.33	1.12 ± 0.24	231.99 ± 53.33	122.88 ± 32.49	93.61 ± 26.36	40.41 ± 11.61	0.0005	0.0267	0.0006
CD at 5%	0.98	0.71	159.87	97.40	79.03	34.80	-	-	-
CV (%)	32.21	36.57	39.81	45.79	48.77	49.75	-	-	-

High temperature stress, or any stress for that matter, is known to adversely affect various physiological processes. The adverse effect of high temperature on plants' metabolic activities leads to reduction in their productivity. Thus, heat stress has been reported to reduce the biomass, leaf area, harvest index, etc. by several workers (Wahid et al. 2007; Farooq et al. 2009; Hasanuzzaman et al. 2013; Jumrani and Bhatia, 2018) [12, 5, 3, 6]. The high temperature tolerant lines tend to have lesser reduction as compared to susceptible lines, or in another terms it can be stated that plants tolerant to high temperature would have higher net assimilation rate, crop growth rate, relative growth rate, and ultimately, higher yield or harvest index. The findings from this experiment are in tune with the results obtained by Sharma et al. (2016) [11] & Kaur et al. (2015) [7] in mungbean.

Conclusion

The results clearly show the difference between the effect of high temperature stress over different growth indices in garden pea genotypes. This was supported by the pod and seed yield produced in these genotypes by the end of the crop (data not presented here). Thus, it can be concluded that growth indices can very well be used as indicators for high temperature tolerance in other crops as well, along with other physiological traits associated with high temperature tolerance as well as susceptibility.

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