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Phenological Development and Thermal Indices in Sesame (*Sesamum indicum* L.) Varieties under different Dates of Sowing

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ABSTRACT: Climate changes are becoming more common in India as a result of global warming. As a result, growth and yield of sesame are affected. Sesame (*Sesamum indicum*) is a short-day plant that grows and yields best in hot weather. Thermal indices are intimately related to crop growth and development. An endeavor to establish a link between thermal indices and sesame crop growth and development could aid in the development of novel varieties that are compatible with changing weather trends. Field experiment was conducted at the Instructional Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner during *Kharif* 2017. The experiment was laid out in a split plot design with three replications. The four dates of sowing (10 July, 20 July and 30 July, and 09 August) were allocated in main plots and four sesame varieties (RT-125, RT- 46, RT-127 and RT-346) in sub plots. Results revealed that timely sown crop had significantly higher values of GDD, PTU, PTI, HTU and HUE at all phenological development stages. Sesame varieties significantly differed in GDD, PTI and HUE. Variety RT-346 and RT-125 require higher GDD and PTI for better response. Higher heat unit efficiency for seed, straw and biological yield found in RT- 125, it was at par with RT-46 and RT-127 as compared to RT-346.

Keywords: Sesame, sowing dates, varieties, GDD, PTU, PTI, HTU, and HUE.

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the oldest and most important oilseed crops. India is now self-sufficient in cereal food production, but it still needs to achieve self-sufficiency in vegetable oil. Globally sesame is cultivated in more than 7 million hectare with an annual production 4 million tonnes. India is the largest producer and area coverage around 26% of sesame in the world. The low yield of sesame varieties under delayed sown conditions leads to discourage growers resulting to less total area under sesame cultivation. The low yield of sesame is mainly due to cultivation of low yielding tradition varieties with lack of improved agronomical practices. The increased availability of improved varieties also increases productivity of sesame. Valiki *et al.* (2015) reported that sesame variety Naz recorded higher yield of 1887 kg/ha than other. During its life cycle, sesame requires a temperature of 25-35°C. When the temperature exceeds 45°C with hot winds the oil content decreases. There is a significant fall in yield when the temperature is above 45°C or below 15°C. (Ranganatha, 2013). It is mostly a tropical crop, though it may be grown in colder climates as well. Premature yield, flower shedding, and pollen sterility may result from abnormally high temperatures during flowering and fruit setting. Although sesame may thrive in long-day conditions, it is commonly thought of as a short-day plant. It takes 45 days to flower under a 10-hour day. Temperature is thought to be the most important driver of crop growth and development among numerous weather variables.

However, various crops are exposed to distinct temperature ranges during different phenological stages, affecting their performance (Mendham *et al.*, 1990; Nanda *et al.*, 1995; Merle *et al.*, 1997; Hocking and Stapper, 2001). With respect to distinct growth and developmental stages, changes in sowing dates result in changes in the crop's thermal environment. Thermal indices *i.e.* growing degree days per accumulated heat unit, heliothermal, phenothermal and photothermal units and heat use efficiency are widely used to predict crop phenology, crop growth rate and yield of several crops (Patel and Mehta, 1987; Perry *et al.*, 1993; Hundal *et al.*, 1997).

Therefore, all growth and developmental stages of crop may be estimated more precise on the basis of growing degree days rather than calendar method (Warthinhton and Hatchinson, 2005). The agronomic application of temperature effect on plants, known as the heat unit concept, has been used to link phonological development in crops and predict maturity dates (Pankaj *et al.*, 2014). The GDD is used to quantify effect of temperature and described the timing of different biological process (Kaur *et al.*, 2006; Qiao-yan *et al.*, 2012). Raut *et al.* (2020) suggested that GDD, HTU, PTU, PTI decreased with delay in sowing after 23rd meteorological week. The present study was carried out in the hyper arid region of Rajasthan to define optimum sesame crop thermal regimes in the form of several temperature-based thermal indices and examine the impact on phenology and yield of four sesame cultivars under varied sowing dates.

MATERIALS AND METHODS

The field experiment was carried out at Instructional Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan, India (28^{o}01′N latitude and 73^{o}22′E longitude at an altitude of 235 meters above mean sea level) during *kharif* season of 2017. The soil of experimental field was loamy-sand, alkaline in nature (pH 8.5) having 118.00 kg/ha available nitrogen (Alkaline permanganate method), low level of available phosphorus (15.10 kg/ha, (Olsen's method) and medium in available potassium (173.70 kg/ha, Flame photometric method) in 0-15 cm soil depth at the start of the experiment. Seed rate of 3 kg ha^{-1} of sesame seed was used for experimentation. The experiment was laid out in a split plot design with three replications. The four dates of sowing (10 July, 20 July and 30 July, and 09 August) were allocated in main plots and four sesame varieties (RT 125, RT 46, RT 127 and RT-346) in sub plots. The sowing of sesame varieties on scheduled dates of sowing and maintained crop geometry 30 ×10 cm. During growing period (July to November) 168.3 mm of rainfall received in 09 rainy days. During the crop season the weekly mean minimum and maximum temperature fluctuated from 15.4 to 47.1°C with the average relative humidity ranged from 16.7 to 85.9 %. Experimental crop was raised as per recommended package of practices.

The daily meteorological data was collected from Agro-meteorological Observatory, ARS, Beechwal, SKRAU, Bikaner. Different agro meteorological indices were calculated on daily basis and accumulated during different phenological stages viz. sowing to emergence, branching, flowering, capsule formation and physiological maturity of the crop using following formulae.

Accumulated heat units or GDD (degree day^{-1})

$$= \sum_{i=1}^{n} \left\{ \frac{(T_{max.} + T_{min.})}{2} - T_b \right\}$$

Where, T_{max} and T_{min} are daily maximum and minimum air temperature, respectively. T_b is the base temperature below which crop growth and development ceases. In case of sesame crop, T_b is 10°C.

Photo thermal units (PTU) = GDD × Day length

Heliothermal unit (HTU) = GDD × Actual sunshine hours

PTI = Accumulated GDD/Number of days between two phenological stages.

Heat use efficiency (HUE) was determined for seed yield, straw yield and biological yield. HUE (Kg/ha °C days) is the dry matter produced per unit degree day consumption which was calculated as – HUE (Kg/ha ºC days) = above ground dry matter (kg/ha)/Accumulated heat units or GDD.

RESULTS AND DISCUSSION

A. Phenological development

The results of the present study showed that delay in sowing decreased the time to attain different phenological stages (Table 2). Phenological development stages of sesame significantly influenced by sowing dates. Sowing on 10 and 20 July attain earlier seedling emergence as compared to 30 July and 09 August. Days taken to 1st branching, 1st flowering, 1st capsule formation and physiological maturity earlier in crop sown on 09 August, in contrast crop sown on 10 July took more days to initiation 1st branching. Thus, data (Table 1) showed that delay in sowing of sesame; earlier attain 1st branching, 1st flowering, 1st capsule formation and physiological maturity than timely sowing. These results were corroborates with the previous findings of Rajput *et al.* (1987), Paul and Sarker (2000), Haidar *et al.* (2003) in wheat, Dahiya and Narwal (1989) in maize, Alam *et al.* (2007) in barley and Akhter *et al.* (2015) in rapeseed. Different varieties of sesame did not differ in phonological development stages.

B. Growing Degree Days (GDD)

Data presented in Table 3 reveals that GDD for different phonological stages differed by sowing dates and varieties. Crop sown on 09 August consumed significantly higher degree days as compared to 10, 20 and 30 July for seedling emergence. Crop sown on 20 and 30 July consumed significantly higher degree days as compared to 09 August, but it was at par with 10 July for attain 1st branching, 1st flowering, 1st capsule formation and physiological maturity, respectively.

Table 1: Mean weekly meteorological data of Bikaner for the year 2017 (*Kharif season*).

SMW	Duration		Temperature (°C)		R.H. (%)		Total Rainfall (mm.)	No. of Rainy days*	Wind Velocity (km./hr.)	Evaporation (mm/day)	BSSH
			Max.	Min.	Max.	Min.					
26	25.06.2017	01.07.2017	37.6	27.3	78.4	49.0	44.2	2.0	5.9	7.1	8.6
27	02.07.2017	08.07.2017	38.6	28.1	71.6	42.6	0.0	0.0	10.8	10.3	10.1
28	09.07.2017	15.07.2017	47.1	28.1	73.7	43.4	0.0	0.0	10.7	9.1	9.3
29	16.07.2017	22.07.2017	38.6	27.0	82.6	48.4	11.7	2.0	4.6	6.9	7.4
30	23.07.2017	29.07.2017	38.5	27.7	83.1	49.6	15.8	1.0	6.4	8.6	9.4
31	30.07.2017	05.08.2017	36.0	26.3	84.3	53.9	0.0	0.0	11.6	6.3	5.8
32	06.08.2017	12.08.2017	37.5	27.8	70.9	45.1	4.4	1.0	11.2	7.9	6.3
33	13.08.2017	19.08.2017	38.6	26.6	72.1	36.1	0.0	0.0	12.0	8.9	10.0
34	20.08.2017	26.08.2017	38.6	26.4	73.0	52.0	59.8	2.0	6.6	9.7	8.5
35	27.08.2017	02.09.2017	34.0	25.5	85.9	60.7	26.4	1.0	6.6	4.6	5.7
36	03.09.2017	09.09.2017	36.5	25.4	78.1	46.3	2.0	0.0	7.4	6.3	8.2
37	10.09.2017	16.09.2017	37.6	24.8	77.7	42.3	4.0	0.0	4.6	6.4	9.0
38	17.09.2017	23.09.2017	40.1	22.3	65.9	23.6	0.0	0.0	3.4	6.6	8.3
39	24.09.2017	30.09.2017	39.3	23.5	61.4	24.4	0.0	0.0	6.5	8.0	9.7
40	01.10.2017	07.10.2017	39.4	21.0	53.4	20.4	0.0	0.0	4.8	7.1	9.9
41	08.10.2017	14.10.2017	39.8	19.9	51.6	16.7	0.0	0.0	3.7	6.3	9.6
42	15.10.2017	21.10.2017	40.2	16.8	44.7	23.4	0.0	0.0	3.3	6.9	10.3
43	22.10.2017	28.10.2017	36.8	16.9	47.1	21.9	0.0	0.0	3.4	5.1	9.8
44	29.10.2017	04.11.2017	35.6	15.4	51.0	20.9	0.0	0.0	3.3	5.4	9.5

* A day having 2.5 mm or more rainfall is considered as a rainy day ; # Data taken from Agro-meteorological Observatory, ARS, Beechwal, Swami Keshwanand Rajasthan Agricultural University, Bikaner.

Table 2: Effect of sowing dates on phenological stages (DAS) of sesame varieties.

Treatments	Seedling Emergence	1st Branching	1st Flower Initiation	1st Capsule Formation	Physiological Maturity
Sowing dates					
10 July	4	30	41	51	84
20 July	4	28	40	50	82
30 July	5	26	38	47	80
09 August	5	24	36	43	79
SEm±	0.1	1	1	1	1
CD (P=0.05)	0.4	2	2	2	2
Varieties					
RT – 125	4	28	39	48	81
RT – 46	4	27	39	48	82
RT – 127	4	26	38	47	81
RT – 346	4	27	39	48	81
SEm±	0.1	1	1	1	1
CD (P=0.05)	NS	NS	NS	NS	NS

NS = Non Significant

Adhikary *et al.* (2020) reported that sesame sowing on 15 February recorded higher GDD values than delayed sowing. Raut *et al.* (2020) found that GDD requirement for different phonological stages differed depending upon the duration of a particular stage. GDD decreased due to late sowing of sesame was also reported by Rajput *et al.* (1987); Paul and Sarker (2000); Haidar *et al.* (2003) in wheat, Dahiya and Narwal (1989) in maize, Borreani *et al.* (2007) in Pea, Alam *et al.* 2007 in barley and Akhter *et al.* (2015) in rapeseed. Further, results revealed that GDD during seedling emergence did not vary in different sesame varieties. Varieties, RT-125 and RT-346 consumed significantly higher degree days as compared to RT-127 and RT-46 for 1st branching. Varieties, RT-125 and RT-346 consumed significantly higher degree days for 1st flowering as compared to RT-127, but it was at par with RT-46. Variety, RT-346 consumed significantly higher degree days for 1st capsule formation as compared to RT-127, but it was at par with RT-125 and RT-46. Sesame variety Rt-346 consumed significantly higher degree days as compared to RT-125, RT-46 and RT-127 for physiological maturity. Adhikary *et al.* (2020) suggested that GDD values differed in different sesame varieties. Similar results also reported by Akhter *et al.* (2015) in rapeseed.

C. Pheno Thermal Index (PTI)

Results revealed that photo thermal index was differed by sowing dates and varieties (Table 4). The photo thermal index was significantly higher in sesame sowing on 10 July, it was at par with 20 July and 30 July and found superior over 09 August for seedling emergence. The photo thermal index for 1st branching was significantly higher in crop sown on 30 July as compared to 10 July; it was at par with 20 July and 09 August.

Table 3: Effect of sowing dates on growing degree days (GDD) (ºC days) of different phenological stages of sesame varieties.

Treatments	Seedling Emergence	1st Branching	1st Flower Initiation	1st Capsule Formation	Physiological Maturity
Sowing dates					
10 July	90.50	630.54	893.95	1087.56	1902.94
20 July	92.25	659.50	931.20	1146.36	1942.33
30 July	92.25	659.50	931.20	1146.36	1942.33
09 August	105.98	516.60	765.33	926.81	1630.50
SEm±	2.22	9.00	13.13	19.51	23.57
CD (P=0.05)	7.69	31.16	45.44	67.51	81.56
Varieties					
RT – 125	96.56	631.88	897.29	1082.29	1765.96
RT – 46	91.29	608.63	880.04	1077.13	1770.90
RT – 127	96.56	593.76	847.06	1050.61	1815.83
RT – 346	96.56	631.88	897.29	1097.08	2065.40
SEm±	1.89	6.10	9.34	9.43	17.18
CD (P=0.05)	NS	17.79	27.25	27.52	50.14

The photo thermal index for 1st flowering was significantly higher in crop sown on 30 July as compared to 09 August; it was at par with 10 and 20 July. Significantly higher photo thermal index for 1st capsule formation was recorded by sowing on 30 July as compared to rest of sowing dates. Crop sown on 20 July recorded higher photo thermal index as compared to 09 August, but it was at par with 10 and 30 July. During the phenological stages, changes in the ambient temperature, even if only for a short time, are reflected in the pheno thermal index. As a result, the index appears to be successful in accounting for and describing the influence of variable ambient temperature on the duration between phenological stages for comparing crop responses to ambient temperature throughout phenological stages. Similar results were also reported by Masoni *et al.* (1990); Bishnoi *et al.* (1995); Paul and Sarker (2000); Haidar *et al.* (2003) in wheat, Dahiya and Narwal (1989) in maize, Alam *et al.* (2007) in barley, Akhter *et al.* (2015) in rapeseed, Malo and Ghosh, (2018) in rice and Raut *et al.* (2020) in sesame.

Among sesame varieties, data showed that photo thermal index for seedling emergence and 1st branching was non-significant in different sesame varieties. Photo thermal index for 1st flowering was higher in RT-346 as compared to RT-46 and 127, but it was at par with RT-125. RT-125 at par with RT-46 and 346 and recorded higher photo thermal index for 1st capsule formation as compared to RT-127. Photo thermal index for physiological maturity was significantly higher in RT-346 as compared to rest of varieties. Findings were correlated with Akhter *et al.* (2015) in rapeseed and Adhikary *et al.* (2020) in sesame.

D. Photo Thermal Units (PTU)

The photo thermal units influenced significantly due to sowing dates (Table 5). Crop sown on 09 August, significantly higher photo thermal units compared to 10, 20 and 30 July. Further, results reveals that sowing on 10 July at par with 20 July and significantly higher photo thermal units for 1st branching, 1st flowering, 1st capsule formation and physiological maturity as compared to 30 July and 09 August, respectively.

Table 4: Effect of sowing dates on pheno thermal index (PTI) of different phenological stages of sesame varieties.

Treatments	Seedling Emergence	1st Branching	1st Flower Initiation	1st Capsule Formation	Physiological Maturity
Sowing dates					
10 July	23.34	24.88	76.17	114.62	58.17
20 July	22.89	27.38	77.93	119.11	60.44
30 July	20.60	30.28	78.90	134.10	59.02
09 August	22.57	27.89	63.43	121.09	46.06
SEm±	0.72	0.87	1.23	3.13	1.62
CD (P=0.05)	2.49	3.01	4.27	10.83	5.59
Varieties					
RT – 125	22.57	27.56	75.47	127.92	53.59
RT – 46	21.46	27.46	71.39	122.31	53.17
RT – 127	23.10	27.56	72.07	117.75	53.46
RT – 346	22.26	27.85	77.50	120.94	63.48
SEm±	0.58	0.72	1.21	2.51	1.22
CD (P=0.05)	NS	NS	3.54	7.33	3.55

NS = Non Significant

Kingra and Kaur (2012) in groundnut, Adhikary *et al.* (2020); Raut *et al.* (2020) in sesame also found similar results. The sesame varieties were non-significant in seedling emergence, 1st branching, 1st flowering, 1st capsule formation and physiological maturity. In all treatments, PTU accumulation increased from emergence to physiological maturity, with the greatest amounts obtained at physiological maturity. Similar findings have also been reported by Srivastava *et al.* (2011) in Mustard and Adhikary *et al.* (2020) in sesame.

Table 5: Effect of sowing dates on photo thermal unit (PTU) (Degree-days hour) of different phenological stages of sesame varieties.

Treatments	Seedling Emergence	1st Branching	1st Flower Initiation	1st Capsule Formation	Physiological Maturity
Sowing dates					
10 July	1243.11	8806.5	12365.18	15070.15	23485.96
20 July	1211.32	8349.8	11695.52	14095.79	22149.30
30 July	1175.00	7677.4	10715.77	12944.17	20826.30
09 August	1392.31	6620.7	9684.93	11648.97	19794.19
SEm±	22.44	133.5	309.01	320.05	399.65
CD (P=0.05)	77.65	462.1	1069.31	1107.51	1382.98
Varieties					
RT – 125	1254.93	7991.3	11304.08	13505.39	21589.22
RT – 46	1256.94	7763.2	11159.07	13441.79	21594.11
RT – 127	1254.93	7708.5	10822.61	13181.98	21536.49
RT – 346	1254.93	7991.3	11175.64	13629.92	21535.92
SEm±	16.67	108.4	199.83	253.45	276.39
CD (P=0.05)	NS	NS	NS	NS	NS

NS = Non Significant

E. Helio Thermal Units (HTU)

The helio-thermal units (HTU) at a particular phenological stage are the product of the duration of sunshine hour of a day and the required accumulated heat units by plants. The helio thermal units at different phonological development stages of sesame influenced due to sowing dates (Table 6). Like GDD, HTU gradually decreased with delay in sowing. Significantly higher helio thermal units for seedling emergence were recorded by 10 July over 20, 30 July and 09 August. Further, results showed that sowing on 10 July at par with 20 July and significantly higher helio thermal units for 1st branching, 1st flowering, 1st capsule formation and physiological maturity as compared to 30 July and 09 August, respectively. HTU decreased at different phenological stages due to delayed in sowing. Similar findings also reported by Rajput *et al.* (1987); Masoni *et al.* (1990); Bishnoi *et al.* (1995); Paul and Sarker (2000); Haidar *et al.* (2003) in wheat, Dahiya and Narwal (1989) in maize, Alam *et al.* (2007) in barley and Akhter *et al.* (2015) in rapeseed, Kaushik *et al.* (2015) in soybean and Adhikary *et al.* (2020) in sesame. Among varieties, sesame varieties were non-significant in all phonological development stages.

Table 6: Effect of sowing dates on helio thermal units (HTU) (Degree-days hour) of different phenological stages of sesame varieties.

Treatments	Seedling Emergence	1st Branching	1st Flower Initiation	1st Capsule Formation	Physiological Maturity
Sowing dates					
10 July	930.68	5176.33	7455.15	9235.58	15061.62
20 July	767.48	4840.82	7147.15	8464.00	14692.00
30 July	321.45	4533.20	6155.07	7789.39	14149.12
09 August	746.49	4281.00	6218.30	7557.71	14510.55
SEm±	9.32	104.50	152.98	228.03	161.37
CD (P=0.05)	32.24	361.62	529.38	789.08	558.43
Varieties					
RT – 125	692.20	4764.57	6896.71	8319.81	14627.47
RT – 46	689.49	4652.34	6769.93	8273.35	14624.84
RT – 127	692.20	4649.86	6511.63	8061.52	14579.66
RT – 346	692.20	4764.57	6797.40	8392.01	14581.31
SEm±	10.21	91.95	111.34	146.55	117.85
CD (P=0.05)	NS	NS	NS	NS	NS

NS = Non Significant

F. Heat Use Efficiency (HUE)

The heat use efficiency values were computed and are presented in Table 7. Heat use efficiency recorded for seed, straw and biological yield was significantly higher in sowing on 10 July as compared to 30 July and 09 August, but it was at par with 20 July. The sowing on 10 July plants used heat more efficiently than the plants of other sowings and the order was 10 > 20 > 30 July >

10 August. The HUE declined with successive delay in sowing and the findings are in conformity with those reported by Rajput *et al.* 1987; Paul and Sarker (2000) in wheat, Roy *et al.* (2005); Neogi *et al.* (2005) in Mustard and Alam *et al.* (2007) in barley, Akhter *et al.* (2015) in rapeseed, Choudhary *et al.* (2018) in mustard and Raut *et al.* (2020) in sesame. Among sesame varieties, RT-125 recorded higher heat unit efficiency for seed yield as compared to rest of tested varieties. Further, variety RT- 46 registered higher heat unit efficiency for straw yield than RT- 346, but it was at par with RT-125 and RT-127. RT-125 recorded higher heat unit efficiency for biological yield as compared RT- 346, but it was at par with RT-46 and RT-127. Results also confirmed with findings of Si and Walton, (2004); Akhter *et al.* (2015) in rapeseed and Choudhary *et al.* (2018) in mustard.

Table 7: Effect of sowing dates on heat use efficiency (HUE) (Kg/ha/ ºC days) of sesame varieties.

Treatments	Seed yield	Straw yield	Biological yield
Sowing dates			
10 July	0.43	1.30	1.72
20 July	0.41	1.24	1.65
30 July	0.27	0.90	1.16
09 August	0.13	0.60	0.73
SEm±	0.01	0.04	0.05
CD (P=0.05)	0.04	0.14	0.17
Varieties			
RT – 125	0.34	1.05	1.40
RT – 46	0.31	1.07	1.36
RT – 127	0.30	1.01	1.31
RT – 346	0.28	0.91	1.19
SEm±	0.01	0.03	0.03
CD (P=0.05)	0.03	0.10	0.09

CONCLUSION

The results of this study show that short-term fluctuations in ambient temperature are reflected in the phenothermal index during each phase of growth. Therefore, the index looks effective during the duration of the phenological occurrence to compare the crop reaction against the ambient temperature between the phenological phases and to reflect the effect of shifting atmospheric temperature. The differences in phenothermal indices for various stages of growth reveal the potential of the accumulated temperature could be utilized for studying biomass accumulation pattern at different phenological stages which ultimately influences the yield potential of crop.

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