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Thermal utilization and heat use efficiency of sesame crop (*Sesamum indicum* L.) under different sowing dates

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Abstract
The field experiment was conducted on experimental farm Department of Agronomy, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during *kharif* season 2017, entitled "Studies on relationship between crop growth, yield and physical environment within the crop canopy of Sesame (*Sesamum indicum L.*) under different weather conditions". An experiment was conducted in randomize block design with six replications. Treatment under study were four sowing dates in *kharif* season i.e. D_1 (23rd MW), D_2 (25th MW), D_3 (27th MW) and D_4 (29th MW), and one variety AKT-64. The results found that all the biometric observations and yield contributing characters such as total number of capsules plant^{-1}, seed yield (kg/ ha^{-1}), straw yield (kg/ ha^{-1}) and biological yield (kg/ ha^{-1}),) significantly highest yield in sown in D_2 (25th MW) followed by D_1 (23rd MW).Sowing at D_2 (25th MW) found superior over the rest of treatments with production of highest grain yield (440.8 kg /ha^{-1}) followed by sowing in first sowing date D_1 (23rd MW) (386.3 kg/ ha^{-1}), third sowing date D_3 (27th MW) (317.8 kg/ ha^{-1}) and lowest grain yield was observed in fourth sowing date D_4 (29th MW) (237.2 kg/ ha^{-1}).The highest GDD was observed in D_1 23th MW sowing date i.e. 2755.5 ^{0}C day. HTU was observed highest in D_1 23th MW i.e. 14298.4 ^{0}C day/hr. PTU was highest in D_1 23th MW i.e. 35069.0 ^{0}C day/hr. PTI observed during total crop growth period was highest in D_1 23th MW i.e. 26.7 ^{0}C as compare to remaining treatments. HUE was highest in D_2 23th MW observed during total crop growth period. In case of date of sowing the highest GDD, HTU, PTU, PTI in D_1 23th MW and HUE was highest in D_2 25 th MW.

Keywords: Yield, GDD, HTU, PTU, PTI and HUE

Introduction
Sesame (*Sesamum indicum* L.) belongs to the family Pedaliaceae and is one of the most ancient oilseed crop used in cooking. The crop has origins in East Africa and India. It is also known as benniseed, ginegelly, simsim, ajonjoli, sesame and til. It was major oilseed crop in the ancient world due to its easiner of extraction, great stability and resistance to drought. Sesame crop cultivated thoughout the year. Crop also cultivated either as a pure stand or as a mixed crop with aus rice, jute, groundnut, millets and sugarcane (Bedigian *et al*, 2003) [2]. sesame requires the optimum temperature during its life cycle is 25-35 ^{0}C. If the temperature is more than 45 ^{0}C with hot winds the oil content reduces. If the temperature goes beyond 45 ^{0}C or less than 15 ^{0}C there is a severe reduction in yield (Ranganatha, 2013) [17] Sesame seed also contain high percentage of some essential amino acids and vitamin B complex, which are important for cell oxygenation influencing liver cell favorably. The chemical composition of sesame seed shows that it seed is a good source of carbohydrate (13.5%), protein (18.25%), ash (5%) and about 50% oil of high quality. Sesame seed also possess the essential fatty acids (EFAS) such as linoleic acid and high lignin that comprises of sesaminol, sesamin, sesamol and sesamolinol. It is a rich source of calcium, protein, vitamin E and contains a little amount of vitamin A, B_1 and B_2 (Morris, 2002) [12]. Among the oilseed crops sesame having 6355 kcal/kg dietary energy in seeds. Sesame oil with 85% unsaturated fatty acid is highly stable and has reducing effect on cholesterol and prevent coronary heat disease. Hence, sesame is called as the "Queen of oil seeds'' by virtue of its excellent quality and utility (Sivagamy *et al* 2013) [19]. A temperature of 25-27 ^{0}C encourage rapid germination, initial growth and flower formation. It can be cultivated in kharif and rabi season. It is capable of withstanding a higher degree of water strees than many other cultivated plants. The seedling stage, however is extremely suceptible to moisture shortage. It will produced an excellent crop with a rainfall of 500-650 mm. Heat use efficiency (HUE), i.e., efficiency of utilization of heat in terms of dry matter accumulation, depends on crop type, genetic factors and sowing time and has great practical application (Rao *et al.*, 1999) [18].

Initiation as well as duration of crop phenophases is an essential component of weather based dynamic crop growth and yield simulation models. Crop phenology can be used to specify the most appropriate date and time of specific development process. The duration of each phenophase determines the accumulation and partitioning of dry matter in different organs (Dalton, 1967) [4]. Wang (1960) [20] reported that the duration of a particular stage of growth was directly related to temperature and this duration of particular species could be predicted using the sum of daily air temperature.

Materials and Methods

The field experiment was conducted in on experimental farm Department of Agronomy, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during *kharif* season 2017, The topography of experimental site was fairly uniform and leveled. The treatment consisting of four sowing dates, i.e 23^{rd} MW, 25^{th} MW, 27^{th} MW, 29^{th} MW with one sesame varietiy - AKT-64 and was sown in Randomize Block design and four replication. After seed bed preparation, sowing was done by drilling. Sesame varieties was sown at 45 cm row to row and 15 cm plant to plant spacing. The seeds was put in soil approximately @ 2-3 cm depth. To maintain optimum plant population thinning and gap filling was carried out keeping only one healthy seedling hill^{-1}. The soil analyzed in experimental field selected for experiment is uniform with typical medium soil having medium fertility and fairly good drainage. fertilizer was applied through nitrogen dose @ 50 kg ha^{-1} urea and single super phosphate @ 25 kg ha^{-1} was applied through at sowing time. The total rainfall during crop growth period i.e. June 2017 to October, 2017 was 994.1 mm received in 43 rainy days. all biometric observation 15 days interval and post-harvest yield attributes observations were recorded at harvest. Agro-meteorological indices were computed for different phenophases of crop.

Growing degree days (^{0}C day) (Nuttonson 1955) [14].

$$GDD\ (^{o}C\ day/hr) = \sum_{i=1}^{n} [(T_{max} + T_{min})/2] - T_b$$

Where,
GDD = Growing degree days
T_{max} = Daily maximum temperature (^{0}C)
T_{min} = Daily minimum temperature (^{0}C)
T_b = Base temperature (10 ^{0}C) (Patel *et al.* 1999) [15].

Helio-thermal Units (HTU) (^{0}C day hrs) Nagamani *et al.* 2015) [13].

HTU (^{o}C day/ hrs) = GDD×BSS

Where,
HTU = Helio Thermal Units
GDD = Growing Degree days
BSS = Bright Sun Shine Hours

Photo Thermal Unit (PTU) (^{0}C day hrs) (Gudadhe *et al.* 2013) [6].

PTU (^{o}C day hrs) = GDD x Day length

Where,
PTU = Photo Thermal Units
GDD = Growing Degree days

Pheno thermal Index (PTI) (Haidar, 2003) [7].

PTI = Ratio of Degree days and number of days between two physiological stages

Heat use efficiency (HUE) (Rajput, 1998) [16].

HUE (kg ha^{-1}°C day $^{-1}$) = GDD / grains of Dry weight.

Results and Discussion

Yields

The data on mean number of capsule/plant, seed, straw and biological yield of sesame as influenced by different sowing dates are given in Table 1. the data indicated that mean number of capsule/plant, seed, straw and biological yield was 20.1, 345.5 kg ha^{-1}, 1077.3 kg ha^{-1} and 1422.4 kg ha^{-1} respectively. Different date of sowing significantly influenced the seeds and straw yields. The sesame sown in D_2 25^{th} MW produced significantly higher seed yield (440.8 kg/ha^{-1}) and followed by D_1 (386.3 kg/ha^{-1}), D_3 (317.8 kg/ha^{-1}) and D_4 (237.2 kg/ha^{-1}). There was reduction in the grain yield in 27^{th} MW and 29^{th} MW. This might be due to delayed sowing as compared to first date of sowing i.e. 25^{th} MW. The straw and biological yield was produced significantly higher in 25^{th} MW as compare to rest of sowing dates. Sowing of sesame during different sowing dates significantly influenced growth and yield contributing characters. These results are similar by Ali *et al.* (2005) [1].

Agro-meteorological indices

Growing degree days (GDD)

Growing degree days (GDD) for sesame crop under different sowing dates from sowing to maturity are presented in Table 2. Data Revealed that the mean total heat requirement during crop life cycle *i.e.* vegetative to Harvesting phenophases (P_1 to P_4) was 2617.4 ^{0}C. The total heat load was Maximum during D_1 23^{th} MW was 2755.5 ^{0}C day and it was followed by D_2 25^{th} MW (2684.7 ^{0}C), D_3 27^{th} MW (2556.8 ^{0}C), and D_4 29^{th} MW (2472.7 ^{0}C) day.
It indicated that the total heat load was decreased from D_1 to D_4 it may be due to delayed sowing occurred during crop life cycle. The GDD requirement for different phenophases varied depending upon the duration of a particular phenophases It may be occurred due to different crop duration, from vegetative to harvesting of such crop Similar results were reported by Borreani *et al* (2007) [3].

Helio-thermal units (HTU)

The Helio-thermal units (HTU)) for sesame crop under different sowing dates from sowing to maturity are presented in Table 3. Data Revealed that the mean total helio-thermal units (HTU) requirement during crop life cycle *i.e.* vegetative to Harvesting phenophases (P_1 to P_4) was 14082.5 ^{0}C day hrs. The total HTU was Maximum during D_1 23^{th} MW was 14298.4 ^{0}C day hrs. The HTU requirement was found to be the highest vegetative phase in the year of experimentation. This was due to the duration, temperature as well as bright sunshine hour available during the period. followed by D_2 25^{th} MW 14013.5 ^{0}C day hrs and D_3 27^{th} MW 13745.9 ^{0}C day hrs. It indicated that HTU was decreased from D_1 to D_3 then increased D_4 29^{th} MW it may be due to delayed sowing occurred during crop life cycle. Similar results were reported by Kaushik *et al* (2015) [8].

Photo-thermal Units (PTU)

The data presented in Table 4. Revealed that mean total Photo-thermal Units (PTU) required in the life cycle i.e vegetative to harvesting phenophases (P_1 to P_4) stage was 32617.3 ^{0}C day hrs for all sowing date. Date of sowing D_1 23th MW required more PTU i.e. 35069.0 ^{0}C day hrs than rest of the treatments, it may be due to maximum air temperature at sowing time. Photothermal unit is the product of growing degree days and day length indicating that higher day length leads to more accumulated PTU. In D_2 23rd MW is 33553.3 ^{0}C day, in D_3 27th MW is 31770.1 ^{0}C day and D_4 29th MW required lowest heat load i.e. 30076.8 ^{0}C day hrs heat unit for attaining various phenophases due to effect of temperature during the crop growing season. Similar results were reported by Kingra *et al* (2012) [9].

Pheno thermal Index (PTI)

The data presented in Table 5. revealed that mean total Pheno thermal index (PTI) required in the life cycle i.e vegetative to Harvesting phenophases (P_1 to P_4) stage was 26.4 °C day^{-1}, being highest in D_1 23rd MW is 26.7 °C day^{-1}, lowest in D_3 27th MW is 26.2 °C day^{-1}. The results of the present study suggest that changes in the ambient temperature even for a short period are reflected in the phenol thermal index during the phenophases. Thus, the index seems to be effective in taking into account and expressing the effect of varying ambient temperature on the duration between the phenological events for comparing the crop response to the ambient temperature between the different phenological stages similar results were reported by Malo *et al* (2018) [11].

Heat Use Efficiency

The data on HUE seed, straw and biological yield of sesame as influenced by different sowing dates are given in Table 6. the data indicated that highest HTU seed, straw and biological yield in D_2 25th MW is 0.16 kg ha^{-1} ^{o}C day^{-1}, 0.47 kg ha^{-1} ^{o}C day^{-1}, and 0.64 kg ha^{-1} ^{o}C day$^{-1.}$ And lowest in D_4 29th MW is 0.10 kg ha^{-1} ^{o}C day^{-1}, 0.33 kg ha^{-1} ^{o}C day^{-1}, and 0.43 kg ha^{-1} ^{o}C day$^{-1.}$ Higher HUE represents that plant utilized the heat more efficiently by increasing biological activity and higher grain yield. Similar result was observed by Girijesh *et al* (2011) [5].

Table 1: Yield attributes of sesame crop as influenced by different treatments

Treatments	Post-harvest Observation			
	No of capsule/plants	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)
D_1: 23rd MW	20.9	386.3	1182.6	1567.4
D_2: 25th MW	22.6	440.8	1268.6	1709.5
D_3: 27th MW	19.2	317.8	1042.9	1360.3
D_4: 29th MW	17.8	237.2	815.2	1052.6
SE ±	0.74	11.7	36.4	57.6
CD at 5%	2.24	35.4	109.8	173.6

Table 2: Growing Degree Day (GDD ^{o}C day) various phenophases in sesame under different date of sowing.

Treatments	Phenophases of sesame				
	(P_1)	(P_2)	(P_3)	(P_4)	Total
D_1: 23rd MW	1306.7	266.1	870.4	312.3	2755.5
D_2: 25th MW	1235.4	261.0	892.7	295.7	2684.7
D_3: 27th MW	1181.9	197.9	889.2	287.9	2556.8
D_4: 29th MW	1145.1	211.1	859.6	257.0	2472.7
Mean	1217.3	234.0	878.0	288.2	2617.4

P_1: Vegetative. P_2: Reproductive. P_3: Maturity. P_4: Harvesting.

Table 3: Helio Thermal Unit (HTU ^{o}C day hrs) various phenophases in sesame under different date of sowing.

Treatments	Phenophases of sesame				
	(P_1)	(P_2)	(P_3)	(P_4)	Total
D_1: 23rd MW	6660.6	1836.1	4177.7	1624.0	14298.4
D_2: 25th MW	6053.5	1070.1	4731.3	2158.6	14013.5
D_3: 27th MW	5200.4	771.8	6046.6	1727.1	13745.9
D_4: 29th MW	5725.5	1477.7	5501.4	1567.7	14272.3
Mean	5910	1288.925	5114.25	1769.3	14082.5

Table 4: Photo Thermal Unit (PTU ^{o}C day hrs) various phenophases in sesame under different date of sowing.

Treatments	Phenophases of sesame				
	(P_1)	(P_2)	(P_3)	(P_4)	Total
D_1: 23rd MW	17117.8	3379.5	10792.9	3778.8	35069.0
D_2: 25th MW	15936.7	3236.4	10890.9	3489.3	33553.3
D_3: 27th MW	15128.3	2454.0	10848.2	3339.6	31770.1
D_4: 29th MW	14428.3	2575.4	10143.3	2929.8	30076.8
Mean	15652.8	2911.3	10668.8	3384.4	32617.3

Table 5: Pheno Thermal index (PTI ^{o}C) various phenophases in sesame under different date of sowing

Treatments	Phenophases of sesame				
	(P_1)	(P_2)	(P_3)	(P_4)	Mean
D_1: 23rd MW	27.8	26.6	26.4	26.0	26.7
D_2: 25th MW	27.5	26.1	26.3	25.7	26.4
D_3: 27th MW	26.9	24.7	26.9	26.2	26.2
D_4: 29th MW	26.6	26.4	26.9	25.7	26.4
Mean	27.2	26.0	26.6	25.2	26.4

Table 6: Heat use efficiency (HUE kg ha^{-1} °C day $^{-1}$) various phenophases in sesame under different date of sowing

Treatments	HUE (Kg ha^{-1} ^{o}C day)		
	Seed	Straw	Biological
Sowing dates			
D_1: 23rd MW	0.14	0.43	0.57
D_2: 25th MW	0.16	0.47	0.64
D_3: 27th MW	0.12	0.41	0.53
D_4: 29th MW	0.10	0.33	0.43

Conclusion

Based on the above findings, it may be concluded that the highest yield was recorded in end of june sowing by sesame D_2 25th MW produced significantly highest yield as compare to rest of sowing dates. it was concluded that with delay in onset of monsoon thermal indices of sesame crops were tend to decline. heat use efficiency and thermal indices point of view D_2 25th MW more efficient to utilize heat units over all the sowing dates. This study also indicated that change in microclimate due to different sowing time is reflected in individual phonological stage.

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