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Physiological and biochemical traits of sesame (*Sesamum indicum* L.) varieties under rainfed conditions

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Abstract
A field experiment was conducted to evaluate the performance of ten sesame varieties *viz*, RT-346, RT-351, RT-127, GT-10, TKG-22, Swetha til, JCSDT-26, DS-1, YLM-66 and KMS-59 for physiological, biochemical and yield traits using randomized block design with three replications under rainfed conditions. Results showed that the varieties significantly differed for the physiological parameters such as photosynthetic rate, stomatal conductance, internal CO_2 concentration where as transpiration rate remain non-significant. Variety JCSDT-26 recorded high photosynthetic rate which is positively correlated with the seed yield and low transpiration rate and internal CO_2 concentration which are negatively correlated with the seed yield. The highest value of oil content was observed in JCSDT-26 (48.5 %) because of its white seed colour. The maximum value of palmitic acid was also recorded in the variety JCSDT-26 (10.57%). Hence, the variety JCSDT-26 is considered as suitable for cultivation under the rainfed conditions.

Keywords: Physiological traits, rainfed conditions, oil content, palmitic acid, sesame

Introduction
Rainfed agriculture dominates global agriculture and plays a critical role in achieving global food security. However growing world population, water scarcity and climate change threaten rainfed farming through increased vulnerability to abiotic stresses. Rainfed areas experience 3 to 4 years of drought in every 10 years. Of these two to three are in moderate and one or two may be of severe stress intensity (Minhas *et al.*, 2017) [13]. About 80% of the world and 60% of the Indian Agriculture is rain-dependent, diverse, complex, under-invested, risky, distress prone and vulnerable (NRAA reports, 2018) [12]. Uncertainties and seasonal migrations have been further compounded due to the high frequency of extreme weather events like droughts due to global warming (IPCC 2018) [7]. Sesame, the ‘queen of oilseeds’ is known for its high oil content and quality (Johnson *et al.*, 1979) [9] belongs to Pedaliaceae family. It is a widely grown crop in tropical and subtropical areas and this crop is documented as the most ancient oil crop providing humans with essential daily energy. Vegetable oil consumption is expected to reach almost 200 billion kilograms by 2030 (Troncoso-Ponce *et al.*. 2011) [19], which will increase the demand for oil-rich crops. Compared to other edible oil crops such as soybean, rapeseed, groundnut and olive, sesame has innately higher oil content (approximately 55% of dry seed) (Wei *et al.*, 2013) [21] and it is also used in therapeutic medicine. The annual area put under it in India is about 1.6 M ha (45 % of the world hectarage) and the total production is 0.78 million tonnes productivity of 501 kg ha^{-1}(AICRP report 2019). Sesame is grown mostly in West Bengal, Uttar Pradesh, Rajasthan, Madhya Pradesh, Telangana, Andhra Pradesh, Maharashtra, Gujarat, Tamil Nadu and Orissa and Karnataka. (Status paper on oilseeds, 2006) [18]. Generally, sesame is cultivated in *kharif* season under rainfed areas with minimum inputs, and crop often expose to water stress and results in low yields. Therefore it is essential to identify the existing variety that adopts the rainfed situation of India.

Materials and methods
An experiment was conducted during kharif, 2018 at ICAR-IIOR Research farm, Narkhoda, Hyderabad. The experiment was laid out in a Randomized Block Design (RBD), replicated

Thrice with a plot size of 12 square meters and the row spacing of 45 cm and intra row spacing of 15 cm. Sowing was done by dibbling and recommended dose of fertilizers were applied (40 Kg N + 20 Kg P_2O_5 + 20 kg K_2O) in two splits and other packages of practices were followed to raise a healthy crop. Prophylactic measures were adopted against pests and diseases. A set of ten sesame varieties including national and local checks were selected for the study. Five random plants from each variety were selected in each replication to record the data on gas exchange parameters *viz.*, photosynthetic rate (Pn), transpiration rate (E), stomatal conductance (Gs) and internal CO_2 concentration (Ci).
The photosynthetic rate was measured at the capsule initiation stage by using Infra-Red Gas Analyser (IRGA; Model-LICOR 6100) from leaves that had fully expanded recently from main stem apex during 10.30 to 13.00 hr (IST) on sunny days. The net exchange of CO_2 between a leaf and the atmosphere is measured by enclosing the leaf in a closed chamber, and monitoring the rate at which the CO_2 concentration in chamber changes over a fairly short time interval. Transpiration rate, stomatal conductance and internal CO_2 concentration measurements were also measured at capsule initiation stage by using Infra-Red Gas Analyser.
SCMR was measured in the same leaf where gas exchange was measured using SPAD meter (SPAD-502; Make:Konica). The oil content was analysed taking 10 grams of seed for each variety by Nuclear Magnetic Resonance (NMR) spectrometer by the modified method of Yadav and Murthy, 2016. Oil from seed was extracted in hexane on a soxhlet apparatus. Methyl esters were obtained according to the method of Anjani and Yadav, 2017. The organic phase was extracted with hexane and washed with water till neutral pH. The hexane was dried over anhydrous sodium sulphate and concentrated with nitrogen gas to get methyl esters. Fatty acid composition was determined using an Agilent 7890B gas chromatograph (GC) equipped with a flame ionization detector (FID) and an auto sampler.

Results and Discussion

Physiological parameters

Assessment of various physiological characteristics of the sesame varieties under rainfed conditions is essential to understand the traits contributing to better yields and can be used for the identification of varieties with better seed yield which are having the adaptability to the rainfed conditions. The maximum values of net photosynthesis were recorded in JCSDT-26 (30.1 µmoles CO_2 m^{-2} s^{-1}) followed by RT-351(29.6 µmoles CO_2 m^{-2} s^{-1}) and Swetha til (29.2 µmoles CO_2 m^{-2} s^{-1}). The minimum values of net photosynthesis were recorded in KMS59 (27.8 µmoles CO_2 m^{-2} s^{-1}), YLM-66 (26.8 µmoles CO_2 m^{-2} s^{-1}) and DS-1 variety (25.8 µmoles CO_2 m^{-2} s^{-1}). Growth, dry matter production and yield depends entirely on photosynthetic rate of crop plants. In the present study photosynthetic rate has a positive correlation with seed yield (R^2: 0.012, (Fig.1). The variations among varieties were also observed. These variations in photosynthetic rates are due to leaf area development of different varieties and the extent of light intercepted by the canopy. These results are in accordance with the studies by Ravitej *et al.*, (2019) [15].
The decreased photosynthetic rate in few varieties can be attributed to reduced SPAD readings. These varieties are incapable to withstand water deficit due to dry spells under rainfed conditions. Both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under water deficit conditions. (Farooq *et al.*, 2009) [6]. The rate of photosynthate is a function of total leaf area and solar radiation intercepted by the crop canopies. These results suggest that the differences in photosynthetic rate among crop varieties are important for understanding the plant capacity to produce economic yield as reported by Islam *et al.*, (1994) [8].
The transpiration rate values revealed that YLM-66 (1.28 m mol H_2O m^{-2} s^{-1}) followed by TKG-22 (1.25 m mol H_2O m^{-2} s^{-1}) and KMS-59 (1.23 m mol H_2O m^{-2} s^{-1}) recorded the highest values whereas Swetha til (1.05 m mol H_2O m^{-2} s^{-1}), RT346 (1.02 m mol H_2O m^{-2} s^{-1}) and JCSDT-26 (1.01 m mol H_2O m^{-2} s^{-1}) recorded the lowest values of transpiration rate. There was no significant difference among the varieties for transpiration rate. The relationship between transpiration rate and yield was found to be negative (Fig. 2), indicating that conservative use of water through transpiration under water scarcity condition due to rainfed situations, those varieties yielded more seed. The similar results were also observed in other oilseeds like groundnut (Ratnakumar and Vadez, 2012; Vadez and Ratnakumar, 2016) [14, 20]
There were significant differences among the varieties for stomatal conductance. The highest values of stomatal conductance were recorded in TKG-22 (0.99 m mol H_2O m^{-2} s^{-1}) followed by RT-127 (0.98 m mol H_2O m^{-2} s^{-1}) and RT-351 (0.92 m mol H_2O m^{-2} s^{-1}). The lowest values were recorded in DS-1 and GT-10 (0.65 m mol H_2O m^{-2} s^{-1}). Stomatal conductance has a negative correlation with yield (Fig. 3). If the stomatal conductance is low there will be faster rate of intercellular CO_2 utilization compared to the rate of CO_2 uptake through stomata. This result is in agreement with the studies made by Akter *et al.*, (2016) [2] in sesame.
The maximum values of internal CO_2 were documented for RT-346 (358 ppm) followed by RT-127 (346 ppm) and TKG-22 (338 ppm). The minimum values were recorded in Swethatil (312 ppm) and JCSDT-26 (306 ppm) and the variety KMS-59 was found to be statistically on par with the variety YLM-66. Internal CO_2 concentration of leaves have negative correlation with yield (fig. 4). There was a significant difference among the varieties for internal CO_2 concentration. Though Ci was low in JCSDT-26 followed by Swethatil, indicated that these varieties were able to fix CO_2 even under lesser stomatal conductance and transpiration.

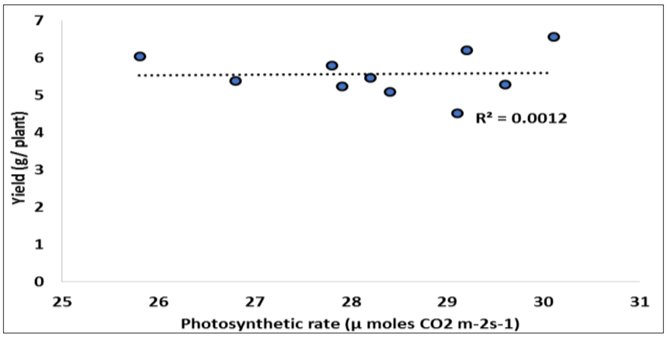

Fig 1: Association between photosynthetic rate at 45 DAS and yield of sesame varieties.

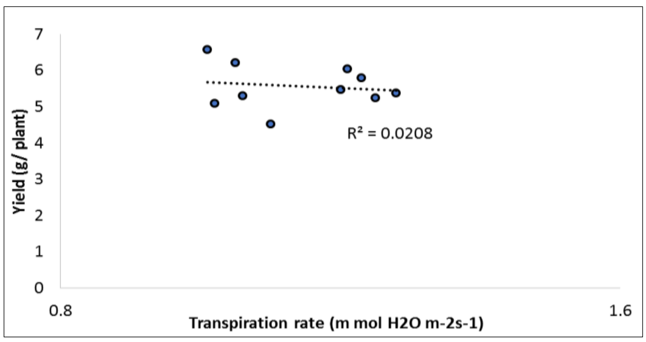

Fig 2: Association between transpiration rates at 45 DAS and yield of sesame varieties.

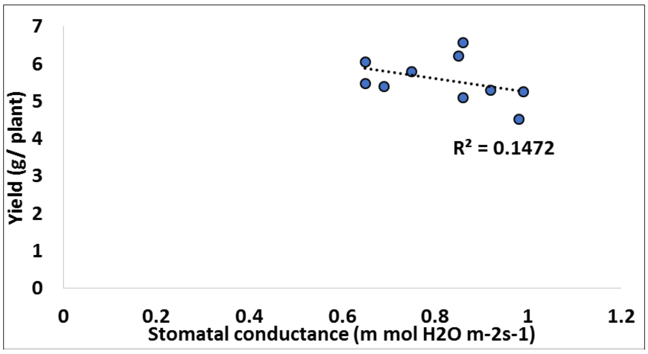

Fig 3: Association between stomatal conductance at 45 DAS and yield of sesame varieties.

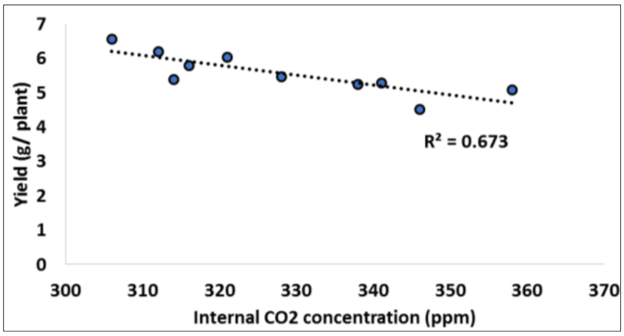

Fig 4: Relationship between internal CO_2 concentration at 45 DAS and yield of sesame varieties.

Oil content and fatty acid profile

There was a significant difference among the varieties for oil content (%). The highest values of oil content was observed in JCSDT-26 (48.5 %) followed by GT-10 (45.03%) and RT-351 (43.9%) under rainfed conditions. The lowest values for oil content (%) were observed in KMS-59 (40.87%) and DS-1 (41.09%). The variety JCSDT-26 is white in colour and has high oil percentage.

These results are in agreement with the results obtained by Akinoso *et al*., (2010) [1], who suggested that oil content in the seeds is associated with the seed colour. Still further conformation is required to confirm oil content based on seed colour. A major cause of the yield reduction under water deficit condition resulting from scarce rainfall could be due to inadequate photosynthesis owing to stomatal closure and consequently limited carbon dioxide uptake (Kadkhodaie *et al*., 2014) [10] and also the results of Connor and Sadras (2016) [4], who reported that a larger amount of abscissic acid, produced in leaves of stressed plants, was translocated to the seeds and led to a decline in the oil/protein ratio of the seeds.

The values of oleic acid content ranged from 24.99 % to 50.73 %, linoleic acid content ranged from 34.33 % to 42.89 % and palmitic acid content ranged from 9.02 % to 10.57 %. Oleic acid is the main mono-unsaturated fatty acid of sesame seed oil (Crews *et al.*, 2006). In this study highest oleic acid percentage was recorded in RT-127 (50.73 %) followed by GT-10 (49.32%) and the lowest percentage was recorded in YLM-66 (45.4 %) and RT-346 (24.99 %). The findings of this study are close to the results of Sowmya *et al.*, (2009) [17]. A Significant negative effect of water stress on oleic acid content in sesame has been reported by Kim *et al.*, (2006) [11]. The maximum values of linoleic acid were recorded in RT-346 (42.89 %) followed by JCSDT-26 (38.85 %) and minimum values were recorded in GT-10 (34.33 %) followed by Swethatil (33.87 %).

These results are in accordance with the studies by Kadkhodaie *et al.*, (2014) [10] who reported that the linoleic acid content of some genotypes increases, while those of other genotypes decreases under water stress conditions. Palmitic acid is the major saturated fatty acid of sesame seed oil (Crews *et al.*, 2006) [5]. The maximum values of palmitic acid were recorded in the variety JCSDT-26 (10.57 %) followed by Swethatil (10.3 %) and the minimum values were recorded in RT346 (9.02 %) . The findings of this study are close to the results of Sowmya *et al.*, (2009) [17]. Palmitic acid contents of oilseed crops depend on the genotype and the level of water stress as suggested by Kadkhodaie *et al.*, (2014) [10].

All the varieties expressed significant difference for seed yield under rainfed conditions. JCSDT-26 has recorded high seed yield (584.58) followed by Swethatil and DS-1 whereas minimum seed yield was recorded in RT-351 followed by RT-346 and RT-127 (402.06). There was significant difference between the varieties for total dry matter and the reduction of total dry matter in some varieties may be due to reduction in rate of photosynthesis under deficit rainfall conditions (Ravitej *et al.*, 2019) [15]. There was significant difference among the varieties for harvest index (HI). Maximum harvest index recorded in varieties is known to be due to higher number of branches and better retention of capsules in sesame (Saha and Bhargava, 1980) [16]

Table 1: Photosynthetic rate (Pn), Transpiration rate (E), Stomatal conductance (Gs) and Internal CO_2 concentration (Ci) of the sesame varieties under rainfed conditions.

S. No.	Varieties	Photosynthetic Rate (µ moles CO_2 m^{-2} s^{-1})	Transpiration Rate (m mol H_2O m^{-2} s^{-1})	Stomatal Conductance (m mol H_2O m^{-2} s^{-1})	Internal CO_2 Concentration (ppm)
1	RT-346	28.4	1.02	0.86	358
2	RT-351	29.6	1.06	0.92	341
3	RT-127	29.1	1.10	0.98	346
4	GT-10	28.2	1.20	0.65	328
5	TKG-22	27.9	1.25	0.99	338
6	Swethatil	29.2	1.05	0.85	312
7	JCSDT-26	30.1	1.01	0.86	306
8	DS-1	25.8	1.21	0.65	321
9	YLM-66	26.8	1.28	0.69	314
10	KMS-59	27.8	1.23	0.75	316
	Mean	28.29	1.14	0.82	328
	S.E.	0.93	0.11	0.04	2.91
	CD(p=0.05)	1.98	NS	0.09	6.16
	CV(%)	4.05	12.32	6.38	1.08

Table 2: Oil content and fatty acid content (Oleic, linoleic and palmitic acid) of the sesame varieties under rainfed conditions.

Sl. No.	Varieties	Oil content (%)	Fatty acidcontent (%)		
			Oleic acid	Linoleic acid	Palmitic acid
1	RT-346	42.44	24.99	42.89	9.02
2	RT-351	43.98	47.50	36.66	9.13
3	RT-127	43.47	50.73	34.85	9.96
4	GT-10	45.03	49.32	34.33	9.67
5	TKG-22	41.79	45.64	38.29	9.96
6	Swethatil	42.67	49.02	33.87	10.31
7	JCSDT-26	48.52	44.21	38.85	10.57
8	DS-1	41.09	46.71	36.70	9.98
9	YLM-66	42.38	45.40	38.47	9.64
10	KMS-59	47.87	45.46	37.83	10.22
	Mean	43.22	44.89	37.27	9.84
	SE	1.14	1.41	1.95	0.43
	CD (p=0.05)	2.39	3.00	4.03	0.98
	CV(%)	3.23	3.86	4.51	1.65

Table 3: Seed yield, Total plant dry matter and Harvest index of the sesame varieties under rainfed conditions.

Sl.No.	Varieties	Total plant dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
1	RT-346	2207.0	453.32	20.56
2	RT-351	2653.4	471.08	17.76
3	RT-127	2482.6	402.06	16.20
4	GT-10	2891.4	486.51	16.82
5	TKG-22	2423.4	466.66	19.26
6	Swethatil	2751.8	560.39	20.38
7	JCSDT-26	3037.2	584.58	19.24
8	DS-1	2836.9	538.36	18.97
9	YLM-66	2263.4	479.70	21.22
10	KMS-59	2590.0	515.54	19.90
	Mean	2613.71	495.82	19.03
	SE	67.51	12.09	0.63
	CD(p=0.05)	142.93	25.60	1.34
	CV(%)	3.16	2.98	2.27

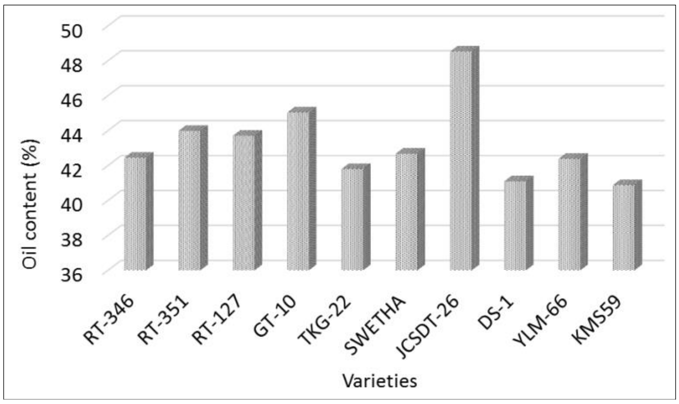

Fig 5: Oil content (%) of sesame varieties.

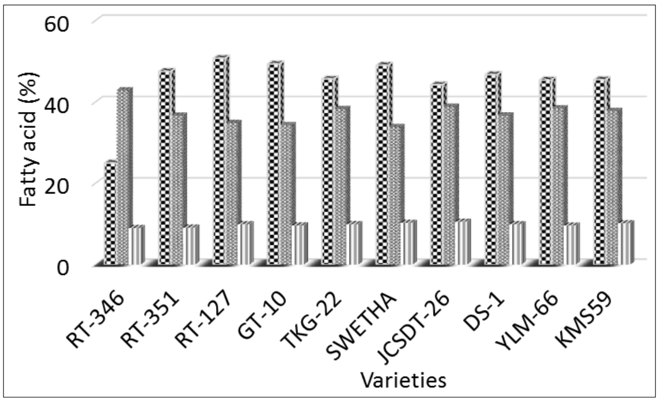

Fig 6: Fatty acid composition of sesame varieties.

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