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RESEARCH ARTICLE

ACCUMULATED THERMAL TIME AFFECTS GROWTH, YIELD AND PHENOLOGICAL DEVELOPMENT OF SESAME (*Sesamum indicum* L.) IN THE DRY ZONE OF SRI LANKA

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ABSTRACT

The present experiment was conducted to determine the impact of accumulated thermal time on the growth, yield and phenology of Sesame (*Sesamum indicum* L.) in the dry zone of Sri Lanka. Uma, Malee and MI-3 varieties were selected and the seeds were sown on three different dates in the 2016 *Yala* and 2016/2017 *Maha* seasons. The experiment was set up according to a two-factor factorial randomized completely block design with three replicates. Accumulated thermal time was calculated as growing degree days at the vegetative stage, flowering initiation, 50% of flowering, 100% of flowering and physiological maturity using minimum and maximum daily temperature. Then the plant height and the number of leaves per plant were plotted against the accumulated thermal time using the sigmoid growth model. The seed dry weight and dry weight of 1000 seeds were recorded at maturity. The relationship of plant height and the number of leaves per plant with accumulated growing degree days (AGDD) was significant for all varieties at different sowing dates in both seasons. The flowering of sesame initiated at 741 and 713.1 of AGDD in *Yala* and *Maha* seasons, respectively. The AGDD needed for 50 % flowering in the *Yala* is greater than the *Maha* season. Full flowering occurred in *Maha* earlier than the *Yala* season. Plants reached physiological maturity early in the *Maha* season. Seed weight per 15 plants and seed weight per plot were significantly affected by the interaction between variety and the sowing date in *Maha* and *Yala* seasons, respectively. The highest seed weight per 15 plants was recorded in var. Uma and var. Malee in *Yala* season while the highest seed weight per plot was also recorded by var. Uma. Furthermore, 1000 seed weight was greater in var. Uma than other varieties in both seasons. Sowing seeds early in the season increased seed weight per 15 plants in *Yala* while seeds per plot and 1000 seed weight in *Maha* season. According to the results of the present study, var. Uma could be considered as an efficient sesame variety that performed better when sown early in the season. Therefore, cultivating var. Uma, early in the seasons might be beneficial in terms of growth and yield in the dry zone of Sri Lanka. However, further field studies are needed to give a solid recommendation.

Keywords: Accumulated thermal time, *Maha* season, Phenology, Sesamum indicum, *Yala* season

INTRODUCTION

Plants need a certain amount of heat for development and shift from one phonological phase to another phase. Farmers take some important management decisions by considering the number of calendar dates more often. However, it is erroneous of using calendar dates, especially in the early crop growth, since temperature changes would affect the duration of some growth stages (Dubey *et al*. 2018; Hatfield and Prueger 2015; Miller *et al*. 2001). Therefore, the ability to predict a specific crop stage would allow taking better management decisions such as fertiliser application and predicting vegetative phase relatively to insect and weed life cycles (Ahmad *et al*. 2017). Sesame cultivation requires a different number of days for growth and development. Different

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planting dates create different sets of environmental conditions, from seedling emergence to physiological maturity (Mulkey *et al*. 1987). Temperature is the driving force behind all biological activities. As a result, the growth, development and reproduction of many organisms are predictable by different heat parameters. Heat value of each day is measured as thermal time and indicated by growing degree days (GDD) (Danneberger and Cushnahan 2014). Thermal time requirement for a given crop is calculated as sum of the growing degree days throughout the growing season. The resulting "thermal time" more consistently predicts when a certain plant stage will occur (Anandhi 2016). Growing degree days are often used as a climate-based indicator to assess crop phenology (Anandhi 2016). The degrees of growth day is used to assess the suitability of a region for the production of a given crop, determine the growth stages of crops, assess the optimum times for the application of fertilizers and herbicides, estimate the accumulation of stress of temperature, predict physiological maturity and harvest dates and use as the ideal meteorological unit in constructing crop models (Parthasarathi *et al*. 2013).

The GDD could be the best tool to predict the phenology of the most of annual plants (Miller *et al*. 2001). Therefore, several GDD predicting models were developed in several countries to explain the future of the growth and development of the cultivations. They had observed increment of GDD with time when simulation of the models (Anandhi 2016; Lalic *et al*. 2016; Paparrizos and Matzarakis 2017). Furthermore, several experiments were conducted by using temperature data for long periods in several countries around the world aiming to find out the impact of climatic change on growing degree days (GDD). They have found that there are offset of GDD with time (Hassan 2007; Bekere *et al*. 2015; Yin *et al*. 2019). The GDD increased due to global warming and that have being focusing matter in agriculture sector due to direct impact of GDD on cultivations (Bekere *et al*. 2015; Yin *et al*. 2019).

Sesame (*Sesamum indicum* L.) belongs to the family of Pedaliaceae, a seasonal and short-day plant having four major phonological phases as vegetative, reproductive, ripening and drying (Langham 2016). Sesame is a drought-tolerant plant and growing mainly in the tropical and subtropical regions of the world, although it can be grown in temperate climates (Hegde 2012; Ashri 1998). Daytime temperatures for optimal growth of sesame should be ranged between 25°C and 27°C (Hegde 2012; Langham 2007; Oplinger *et al*. 1990). Sesame is a short day plant with the 10 hours per day of optimal photoperiod (Hegde 2012; Langham 2007) and normally cultivates as a low altitude crop which are growing below 1250m. However, it can be cultivated in areas with high altitudes in Nepal and India. Sesame plants in high altitude are relatively small in size and unbranched with low seed yield while the length of the life cycle is also short (Hegde 2012). Though *S. indicum* typically requires rather warm conditions for optimal growth and yield (Bahrami *et al*. 2012), the abnormally high temperature during sesame flowering may lose of flowers, loss of pollen sterility and lead to premature yields (Kumazaki *et al*. 2008). Sesame is a drought-tolerant crop but requires sufficient moisture for germination and early growth. Therefore, rainfall in between 500 mm to 650mm is needed. However, sesame is intolerant to water logging conditions (Oplinger *et al*. 1990). Sesame has been used as a condiment flavour agent and traditional medicine in Sri Lanka. It is mainly cultivated on a small scale and the production is slightly more than 1t ha-1. Land extent for sesame cultivation in Sri Lanka is around 6,035 ha in 2019 while the total annual production is 6,085 t. The Anuradhapura district contributed the highest, 1904 ha, to the total land extent (AgStat 2020). Further, the land extent of Sesame cultivation in *Yala* season is greater than *Maha* season. It is cultivated as a secondary crop in *Yala* season and as a primary crop grown during *Maha* season (Dissanayake *et al*. 2017). Sesame could give reasonable yield under dry conditions with over high temperature and limited soil moisture due to low rainfall (Bahrami *et al*. 2012). Temperature is a crucial abiotic factor that influences growth and development of sesame.

Sri Lanka is an agricultural country with two-third of its total land area belonging to the dry zone that experiences less than 1750 mm of annual precipitation with a dry period in May to September. According to the Center for Socio-Economic Planning, 14 out of 19 districts cultivate sesame belonged to dry zone in 2019 (AgStat 2020). The current study was carried out to determine the necessary demand of growing degree days for different phenological stages of selected sesame varieties while investigating the effect of growing degree days on sesame growth and yield in the dry zone of Sri Lanka.

MATERIALS AND METHODS

Experiment site and treatments

The present experiment was conducted in the fields of Grain Legumes and Oil Crops Research and Development Center, Angunakolapelessa located in Hambantota district of southern province, Sri Lanka. In this area, rolling and undulating land patterns could be identified with Red Brown Earth and Low Humic Gray soils. Angunakolapelessa belongs to low country dry zone and in agro-ecological region DL1b (Natural Resource Management Center, 2003). Three commercial varieties (var. Uma, Malee and MI-3) were cultivated at three different sowing dates (early, mid and late of the particular season) in 2016 *Yala* and 2016/2017 *Maha* seasons (hereafter *Yala* & *Maha*). The *Maha* season falls during Northeast monsoon from September to March while the effective period of *Yala* season is May to September parallel to Southwest monsoon in Sri Lanka. The size of the plot was 4 m x 3 m and the spacing of planting was 30 cm x 20 cm. The experiment was set up according to two-factor factorial randomized completely block design with three replicates. Factor one was the variety while factor two was the sowing date. Table 1 shows the details of different treatment combinations applied in the experiment for both seasons. The experiment was carried out for 16 weeks in each season.

Measured parameters

Accumulated thermal time as growing degree days (GDD, °Cd) was calculated throughout the experiment in two weeks intervals. The mean day temperature was calculated by dividing the sum of maximum and minimum temperature for the day by two. Then, the thermal time was calculated by subtracting the base temperature from the mean day temperature. After that accumulated thermal time was calculated by summing up the thermal time of a particular period as accumulated growing degree days (AGDD) (Equation 1). Accordingly, AGDD at relevant different growth stages; vegetative phase, flowering initiation, 50% flowering, 100% flowering and physiological maturity were

Table 1: Treatment combinations of the experiment conducted in *Yala* season 2016 and *Maha* season 2016/2017

Treatment combinations	*Yala* Season 2016		*Maha* Season 2016/2017	
	Factor 1 (Variety)	Factor 2 (Sowing date)	Factor 1 (Variety)	Factor 2 (Sowing date)
T1	Uma	07 April 2016	Uma	21 October 2016
T2	Uma	21 April 2016	Uma	04 November 2016
T3	Uma	05 May 2016	Uma	18 November 2016
T4	Malee	07 April 2016	Malee	21 October 2016
T5	Malee	21 April 2016	Malee	04 November 2016
T6	Malee	05 May 2016	Malee	18 November 2016
T7	MI-3	07 April 2016	MI-3	21 October 2016
T8	MI-3	21 April 2016	MI-3	04 November 2016
T9	MI-3	05 May 2016	MI-3	18 November 2016

identified based on the sowing dates. Fifteen plants were randomly selected to measure the plant height (cm) and the number of leaves per plant at different growth phases mentioned manually. Seed weight of 15 plants (g), seed weight of the plot (g) and 1000 seed weight (TSW; g) were measured during harvesting.

$$AGDD = \sum_{Day\,i}^{Day\,j} \left\{ \frac{T_{max} + T_{min}}{2} - T_{base} \right\} \ldots \textbf{\textit{Eqn. 1}}$$

Where;
T_{max} = *Maximum daily temperature,* T_{min} = *Minimum daily temperature,* T_{base} = *Base temperature (10°C), i/j = 1, 2…*

Then, the plant height and the number of leaves per plant were plotted against the accumulated thermal time using sigmoid growth model (non-linear relationship) (Equation 2) (Meena and Rao 2013).

$$y = \frac{a}{\left(1 + \exp\left(\frac{-(x - x_0)}{b}\right)\right)} \ldots \textbf{\textit{Eqn. 2}}$$

Where;
Y = Growth parameter (plant height or number of leaves), x = accumulated Thermal time (Growing degree days; °Cd), x_0, *a and b = parameters of sigmoid growth model*

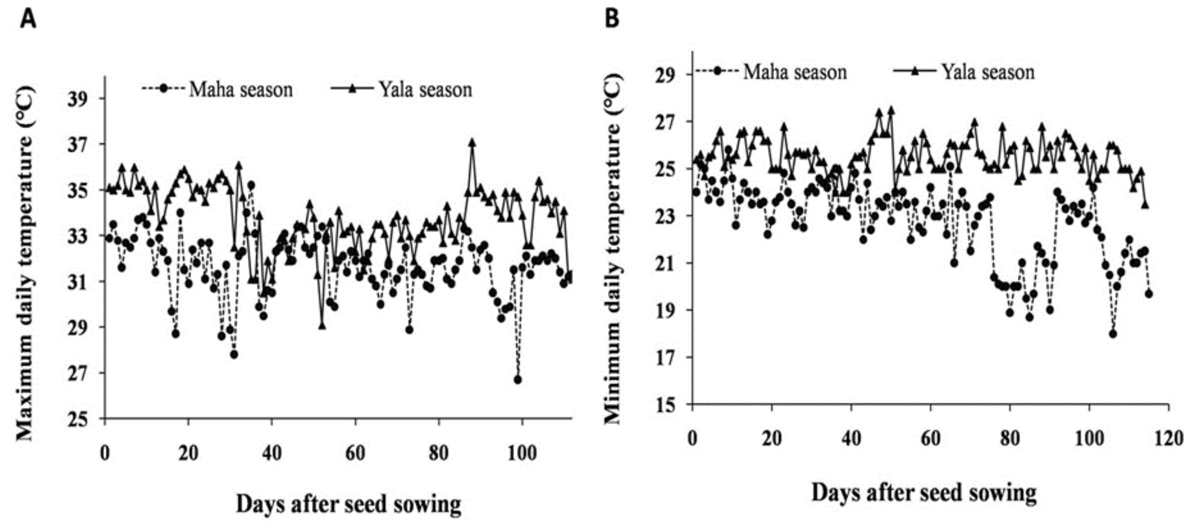
Statistical analysis
Treatment effect on plant growth and yield were tested according to the analysis of variance. Relationship between growing degree days and plant growth parameters was analyzed by non- linear regression procedure. SAS university edition was used to analyze the data.

RESULTS AND DISCUSSION

Meteorological data of the experimental site
Meteorological data during the *Yala* season and *Maha* season were obtained from weather station at Grain Legumes and Oil Crops Research and Development center at Angunakolapelessa. Figure 1 (A) shows the maximum temperature, minimum temperature and average daily rainfall of the study area three months period from seed sowing to harvesting. The maximum temperature was significantly high in the *Yala* season than in the *Maha* season. The gap between maximum temperature in two seasons in the beginning and the end of the growing season is greater than the middle of the season. The average minimum temperature throughout the *Yala* season was greater than the *Maha* season (Fig. 1B). *Maha* season received high rainfall compared to the *Yala* season. However, the greater rainfall received in the 4th week to the 6th week of the *Yala* season. The early and later phases of the *Maha* season had received more rainfall than the middle phase (Fig. 1C).

Length of growth and development of sesame may depend on climatic factors such as growing degree days, temperature, rainfall and relative humidity. Soil parameters such as soil type, soil moisture content and fertility and management practices such as spacing are also affected on the growth and development. Langham (2016) reported that the germination period increased with high soil moisture content. Therefore planting time is very critical. The growth of the plant and yield may be affected by planting time (Mulkey *et al*. 1987). According to Langham (2007), seed germination would be enhanced by soil temperature. Further, it is explained that vegetative and reproductive stages could be lengthened by increasing Growing degree days. When night temperature drops significantly, the time spent for ripening and full maturity may increase (Langham 2016).

Plant height and number of leaves per plant
The relationship of plant height (Fig. 2, 3 and 4) and the number of leaves per plant (Table 2) with accumulated growing degree days (AGDD) was significant for all varieties at different sowing dates in both seasons. Therefore, height and the number of leaves per plant were significantly affected by AGDD. Results of the previous studies were in line with the findings of the present study (Pandey and Paul 2017; Gloaguen *et al*. 2018). Meena and Rao (2013) suggested that



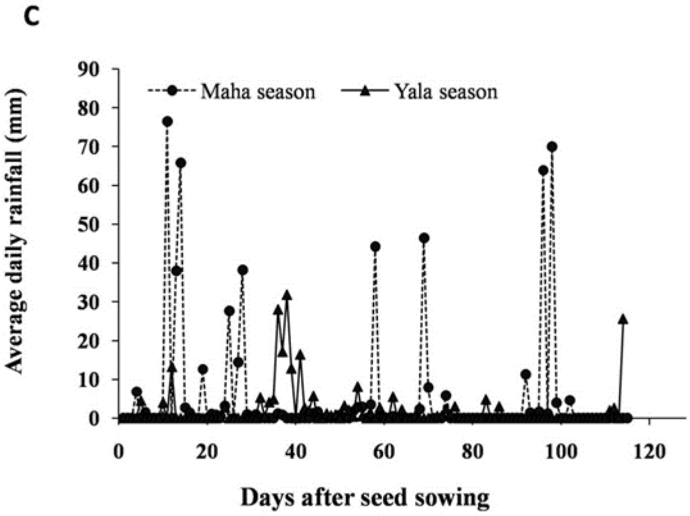


Figure 1: (A) Maximum daily temperature, (B) Minimum daily temperature and (C) average daily rainfall of the study area for 2016 *Yala* season and 2016/2017 *Maha* season against the days after seed sowing

AGDD is more important for plant growth than the number of days after seed sowing. Further, the results of the present study showed that selected growth parameters could be predicted by growing degree days and it would be the most accurate method to predict growth parameters (Dutta *et al*. 2011; Basu *et al*. 2012). It would be useful when taking agronomical decisions including the identification of planting season and the date (Langham 2007; Meena and Rao 2013).

Phenological development

Table 3 shows the accumulated thermal time (AGDD) of different treatments at both seasons. According to that, var. Uma needed the lowest AGDD values to end the seedling stage in both seasons. When seeds sown early in the season, plants shift from the seedling stage to the next growth stage faster than the late sowing dates for all varieties in both seasons. However, relatively less AGDD was required for all varieties to reach the vegetative stage in *Maha* season at all sowing dates. In general, the vegetative stage was lengthened than usual in both seasons.

According to Table 4, the flowering of Uma was initiated by relatively low AGDD than other varieties in both seasons. Furthermore, the time taken for shifting from one growth stage to another stage was much quicker when seeds were sown in early date in both seasons. The vegetative phase would be over when 50% of plants initiated the flowering while the reproductive phase started. Table 4 shows the GDD from seed sowing to 50% flowering for different treatments. The lowest AGDD was

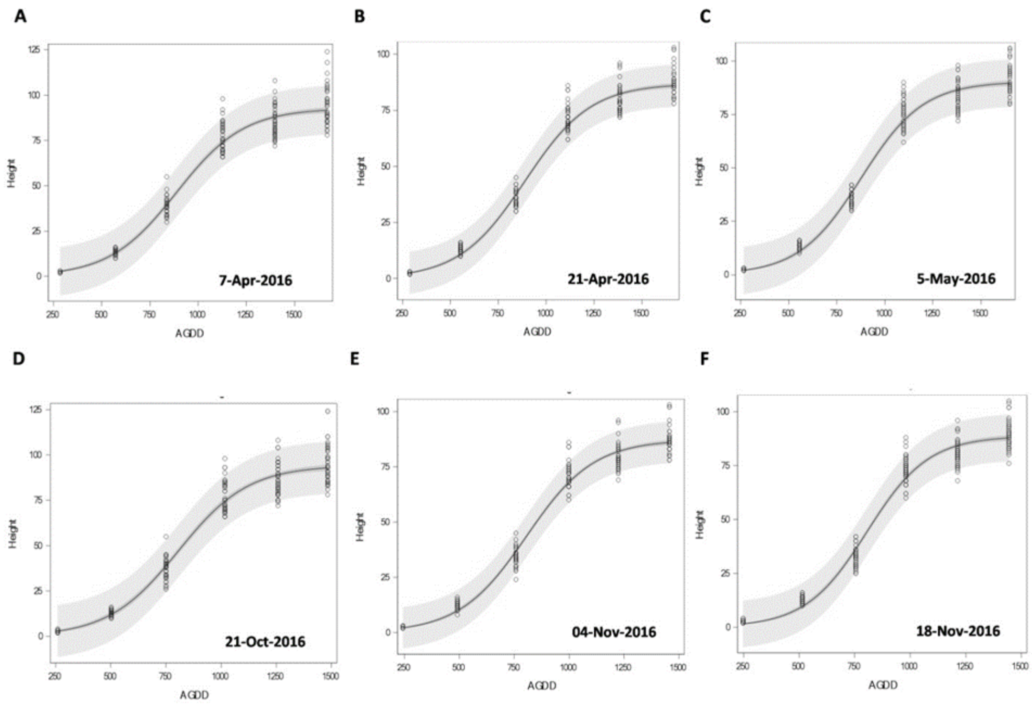


Figure 2: Observed values and fitted curves for plant height of variety Uma against accumulated thermal time (^{o}Cd) for different sowing dates in *Yala/Maha* seasons (A) 7th April 2016 (B) 21st April 2016 (C) 5th May 2016 (D) 21st October 2016 (E) 4th November 2016 and (F) 18th November 2016.

Table 2: Estimated parameters of sigmoid growth model for number of leaves per plant of three varieties (Uma, Malee and MI-3) in three sowing dates in *Yala* (07 April 2016, 21 April 2016 and 05 May 2016) and *Maha* (21 October 2016, 04 November 2016 and 18 November 2016) seasons

Season	Sowing Date	Variety	Parameters			F value	P value
			a	b	X_0		
Yala Season	07 April 2016	Uma	46.63	263.71	1004.54	9042.36	<0.001
		Malee	40.14	247.34	971.92	9146.15	<0.001
		MI-3	38.07	232.40	936.37	7578.86	<0.001
	21 April 2016	Uma	47.72	299.91	1082.65	6783.52	<0.001
		Malee	39.28	266.17	1004.43	5767.04	<0.001
		MI-3	37.97	239.12	966.01	9443.04	<0.001
	05 May 2016	Uma	44.14	277.70	1053.27	12815.20	<0.001
		Malee	40.41	262.61	1020.54	10952.50	<0.001
		MI-3	38.76	256.90	1008.60	13673.10	<0.001
Maha Season	21 October 2016	Uma	45.00	246.22	909.32	9896.63	<0.001
		Malee	40.24	227.91	876.45	8089.98	<0.001
		MI-3	40.53	219.95	858.23	7500.38	<0.001
	04 November	Uma	46.56	256.93	953.39	6679.68	<0.001
		Malee	41.66	241.25	926.83	6265.16	<0.001
		MI-3	39.74	227.65	893.40	7681.97	<0.001
	18 November 2016	Uma	43.58	237.21	948.62	10730.40	<0.001
		Malee	40.11	220.86	913.80	12639.00	<0.001
		MI-3	40.58	223.10	916.44	10996.70	<0.001

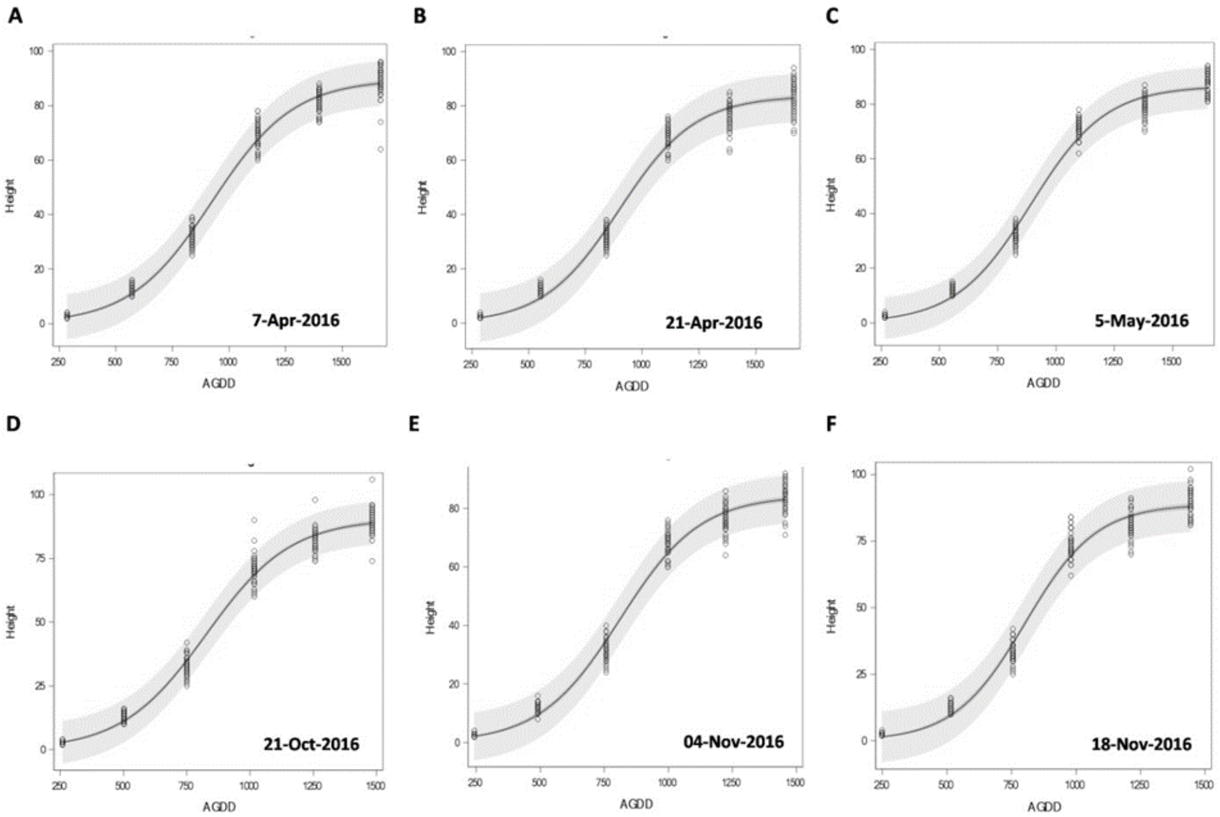


Figure 3: Observed values and fitted curves for plant height of variety Malee against accumulated thermal time (°Cd) for different sowing dates in *Yala/Maha* seasons (A) 7th April 2016 (B) 21st April 2016 (C) 5th May 2016 (D) 21st October 2016 (E) 4th November 2016 and (F) 18th November 2016

needed for var. Uma to achieve 50% of flowering. GDD requirement to move into the next stage is relatively low when seeds were sown early in the season (Table 5).

Around 80% of flowers opened at the end of the reproductive stage (Langham *et al*. 2008) and the most productive stage. Flowering and capsule development both would occur on the main stem and branches during this stage. Therefore, the plants should be strictly protected from stress during this stage. If the moisture is running out, the number of flowers that opens a day will reduce (Langham 2007). Furthermore, the reproductive phase is extended until physical maturity occurred. This phase also consisted of 3 stages and the reproductive phase would be over when 90% of plants terminate the flowering.

Table 3: Accumulated thermal time as growing degree days (AGDD) from seed sowing to beginning of the vegetative stage of three varieties at three sowing dates in *Yala* and *Maha* season. Time taken for reaching to the particular stage is given as number of days after seed sowing (DAS)

Season	Sowing date	Uma		Malee		MI-3	
		AGDD	DAS	AGDD	DAS	AGDD	DAS
Yala	07 April 2016	509.50	25	550.51	27	550.50	27
	21 April 2016	515.70	26	552.83	28	572.00	29
	05 May 2016	536.50	28	555.66	29	575.40	30
Maha	21 October 2016	452.75	25	486.65	27	486.65	27
	04 November 2016	472.65	27	508.34	29	508.30	29
	18 November 2016	513.15	29	530.02	30	530.00	30

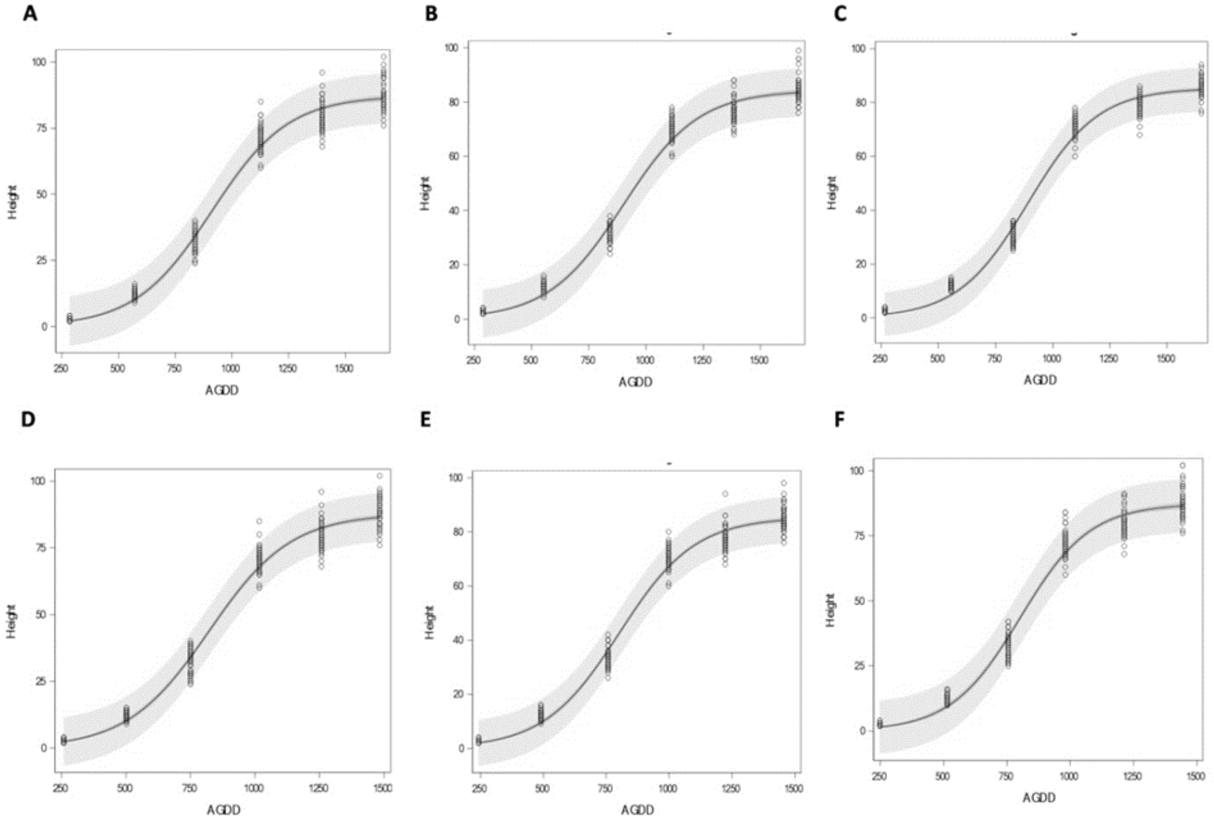


Figure 4: Observed values and fitted curves for plant height of variety MI-3 against accumulated thermal time (^{o}Cd) for different sowing dates in *Yala/Maha* seasons (A) 7th April 2016 (B) 21st April 2016 (C) 5th May 2016 (D) 21st October *2016* E) 4th November 2016 and (F) 18th November 2016

In the *Yala* season, all of the plants of every variety at all sowing dates were completed the flowering at the beginning of the 9th week after seed sowing. Var. Uma recorded the lowest AGDD among varieties in both seasons. Var. Malee and var. MI-3 showed the same intention about AGDD regard to 100% flowering (Table 6).

Table 7 shows AGDD at physiological maturity of all treatments. Var. Uma was the variety that needed the lowest AGDD to reach physiological maturity. AGDD was not significantly different among sowing dates, but the number of days after sowing was different. AGDD was lower in the *Maha*

Table 4: Accumulated thermal time as growing degree days (AGDD) from seed sowing to beginning of the flowering of three varieties at three sowing dates in *Yala* and *Maha* season

Season	Sowing Date	Uma		Malee		MI-3	
		AGDD	DAP	AGDD	DAP	AGDD	DAP
Yala	07 April 2016	726.04	36	745.41	37	745.41	37
	21 April 2016	730.72	37	748.38	38	748.34	38
	05 May 2016	728.74	38	747.74	39	747.77	39
Maha	21 October 2016	696.21	39	713.53	40	713.52	40
	04 November 2016	689.55	39	722.28	41	722.25	41
	18 November 2016	703.63	40	736.81	42	720.52	41

Table 5: Accumulated thermal time as growing degree days (AGDD) from seed sowing to 50% of the flowering of three varieties at three sowing dates in *Yala* and *Maha* season. Time taken for reaching to the particular stage is given as number of days after seed sowing (DAS)

Season	Sowing Date	Uma		Malee		MI-3	
		AGDD	DAS	AGDD	DAS	AGDD	DAS
Yala	07 April 2016	914.15	46	954.45	48	954.45	48
	21 April 2016	920.32	47	957.65	49	957.65	49
	05 May 2016	922.27	48	961.67	50	961.67	50
Maha	21 October 2016	893.55	50	912.05	51	912.05	51
	04 November 2016	896.92	51	912.46	52	912.43	52
	18 November 2016	900.85	52	916.84	53	900.87	52

season, but the duration was higher than the *Yala* season for AGDD amount. Sesame is a quantitative short-day annual and it would be dried out 5 months after planting (Langham 2007; Suddihiyam *et al*. 1992). Plants that flowering is encouraged by that short-day condition, but they could be flowering even under long photoperiods are defined as quantitative short day plants (Hopkins and Huner 2008). During plant growth, many morphological differences have occurred at different growth stage from seed germination to the drying stage. The length of any growth stage is always not unique because duration would be affected by different genetics, agronomical and environmental factors (Hegde 2012; Weiss 2000; Mulkey *et al*. 1987). There are four major phases in sesame phenology up to the harvesting stage (Langham 2007; Attibayeba *et al*. 2010).

The drying phase is divided into three stages which are full maturity, initial dry-down and late dry-down. This phase is lengthening from physiological maturity until complete dry-down (Langham *et al*. 2008). This phase also extending due to high moisture availability, high humidity, low temperature, and lesser sunshine and duration would be reduced by the opposite conditions (Langham 2007).

Yield parameters of sesame

The interaction effect between variety and the sowing date (V x SD) was not significantly different among treatments for the seed weight of the 15 plants in the *Yala* season. However, there was a significant difference among varieties ($P < 0.001$; Fig. 5A) and sowing dates ($P < 0.01$; Fig. 5B) for the seed yield of 15 plants. Var. Uma (37.03 g + 1.50) and Male (34.79 g + 2.12) recorded significantly high seed weight per 15 plants compared to MI-3 (24.52 g + 1.56). Early sowing date in the *Yala* season seems to have a positive effect on seed weight. Hence, the highest seed weight per 15 plants was

Table 6: Accumulated thermal time as growing degree days (AGDD) from seed sowing to 100% of the flowering of three varieties at three sowing dates in *Yala* and *Maha* season. Time taken for reaching to the particular stage is given as number of days after seed sowing (DAS)

Season	Sowing date	Uma		Malee		MI-3	
		AGDD	DAS	AGDD	DAS	AGDD	DAS
Yala	07 April 2016	1068.95	54	1107.65	56	1087.51	55
	21 April 2016	1072.97	54	1092.77	56	1092.77	56
	05 May 2016	1077.87	56	1097.72	57	1097.72	57
Maha	21 October 2016	1033.5	58	1069.31	60	1051.25	59
	04 November 2016	1031.85	59	1066.95	61	1049.25	60
	18 November 2016	1030.05	60	1078.73	63	1046.25	61

Table 7: Accumulated thermal time as growing degree days (AGDD) from seed sowing to physiological maturity of three varieties at three sowing dates in *Yala* and *Maha* season. Time taken for reaching to the particular stage is given as number of days after seed sowing (DAS)

Season	Sowing Date	Uma		Malee		MI-3	
		AGDD	DAS	AGDD	DAS	AGDD	DAS
Yala	07 April 2016	1417.52	72	1668.87	82	1688.12	86
	21 April 2016	1423.22	73	1666.62	82	1686.92	86
	05 May 2016	1418.97	73	1668.07	83	1686.07	87
Maha	21 October 2016	1326.37	75	1451.86	83	1582.25	91
	04 November 016	1322.86	77	1456.42	85	1589.05	93
	18 November 2016	1328.85	78	1459.73	86	1583.05	93

observed when seeds were sown on 7th April 2016 (37.01 g + 2.21) than on 21st April 2016 (31.02 g + 2.62) or 5th May 2016 (28.32 g + 1.90). In the *Maha* season, the interaction between variety and the sowing date (P<0.05) was significant for seed weight per 15 plants (Fig. 5C).

Seed dry weight per plot was significantly affected by the interaction between variety and the sowing date (P<0.01; Fig. 6A) in the *Yala* season but not in the *Maha* season. However, the variety (P<0.001; Fig. 6B) and the sowing date (P<0.001; Fig. 6C)

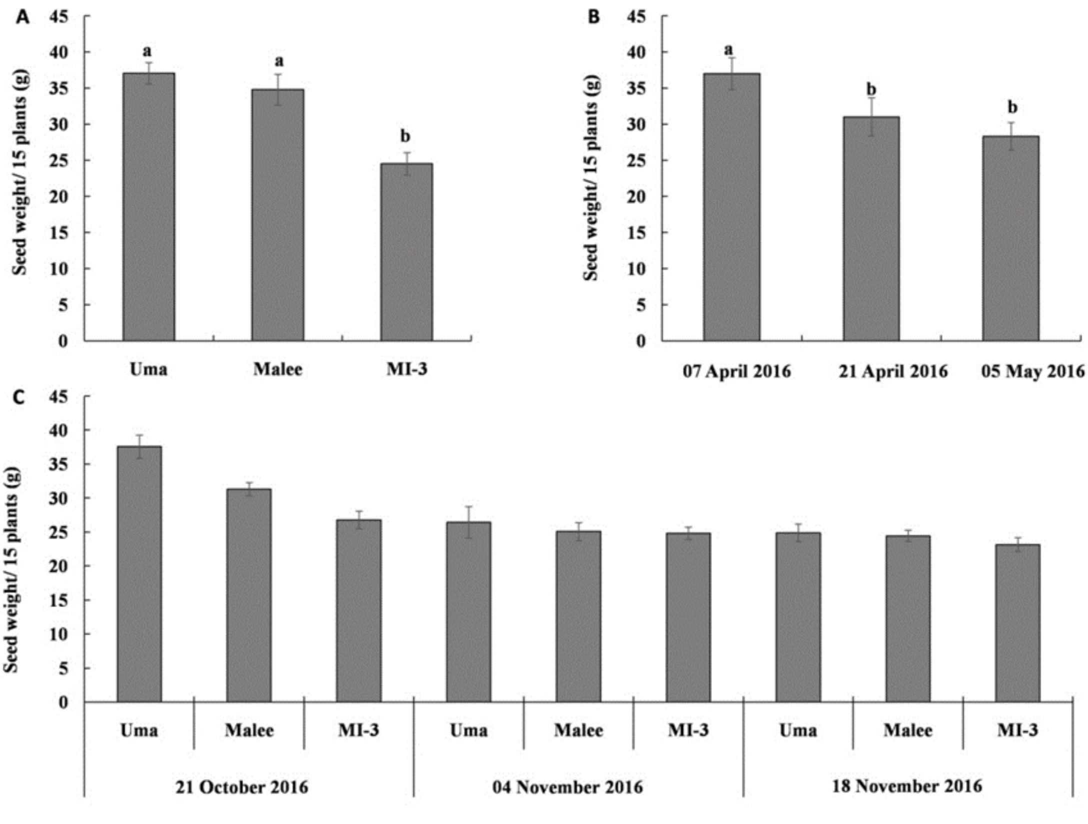


Figure 5: Seed dry weight of 15 plants as affected by (A) variety (B) sowing date in *Yala* season 2016 and (C) interaction effect between variety and sowing date in *Maha* season 2016/2017. Ear bars indicate stand error of the means. Means with same letters are not significantly different at α=0.05 as Duncan Multiple Range Test

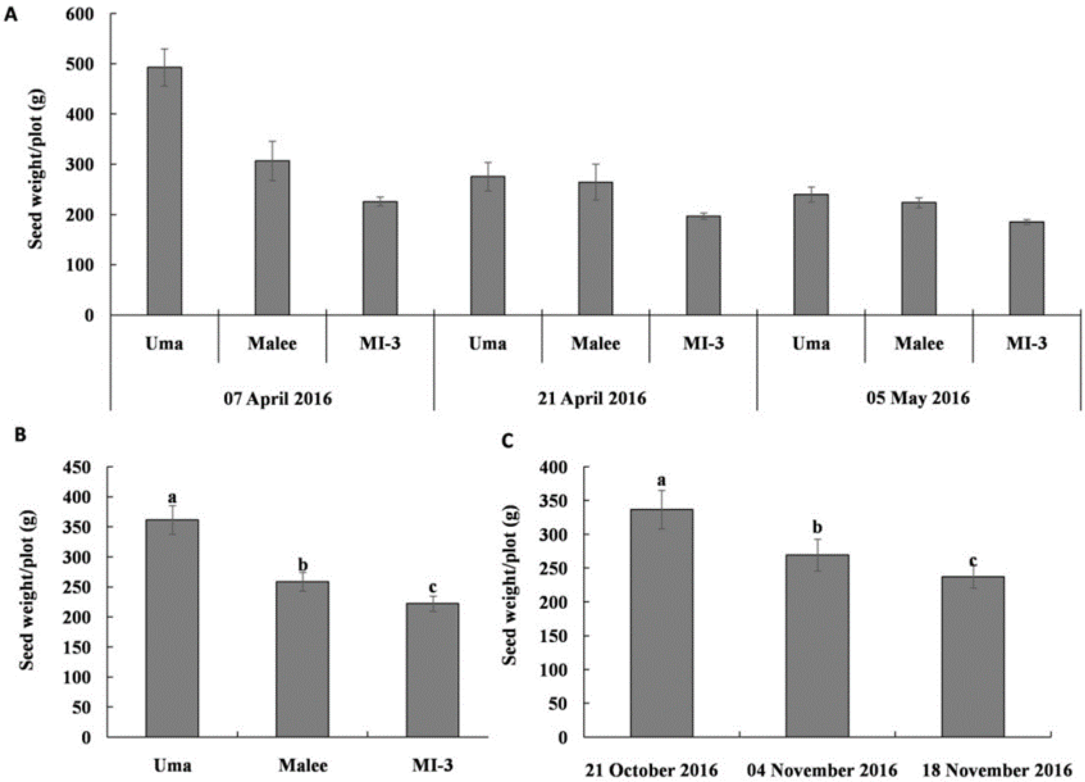


Figure 6: Seed dry weight per plot as affected by (A) interaction between variety and sowing date in *Yala* season 2016 (B) varietal effect on seed weight per plot and (C) effect of sowing date on seed weight per plot in *Maha* season 2016/2017. Ear bars indicate stand error of the means. Means with same letters are not significantly different at α=0.05 as Duncan Multiple Range Test

significantly influenced the dry weight per plot in the *Maha* season. The highest seed weight per plot was recorded by variety var. Uma and the lowest weight by var. MI-3. When seeds sowed early in the season, the seed weight of the plot were high when compared to late sowing dates in the *Maha* season. The mean seed weight per plot was significantly different between the three sowing dates.

The interaction effect of variety and sowing date for 1000 seed weight was not significant in both seasons. However, the varietal effect on 1000 seed weight was significant in the *Yala* season ($P<0.001$; Fig. 7A) while both variety ($P<0.01$; Fig. 7B) and the sowing date ($P<0.01$; Fig. 7C) significantly influenced the 1000 seed weight in the *Maha* season.

There was no interaction effect between variety and the sowing date for AGDD requirement and the number of days after sowing to reach into physiological maturity of the crop in both seasons. However, the variety ($P<0.001$) and the sowing date ($P<0.001$) had significant variation in both seasons. According to that, in both seasons, AGDD requirement of var. Uma to reach physiological maturity was significantly lower than the other two varieties. Hence, var. Uma needs fewer days from seed sowing to maturity. At the same time, var. MI-3 needed high AGDD and took approximately 14 more days to reach to maturity in both seasons. Vora *et al*. (2018), based on a two-year field study in India on heat requirement of short duration crops of sesame, black gram and pearl millet together with long duration crops of cotton, castor and groundnut found that the highest growing degree days, the highest efficiency of heat use and the highest yield for both types of crops recorded at early planting dates. It was suggested that the early sown

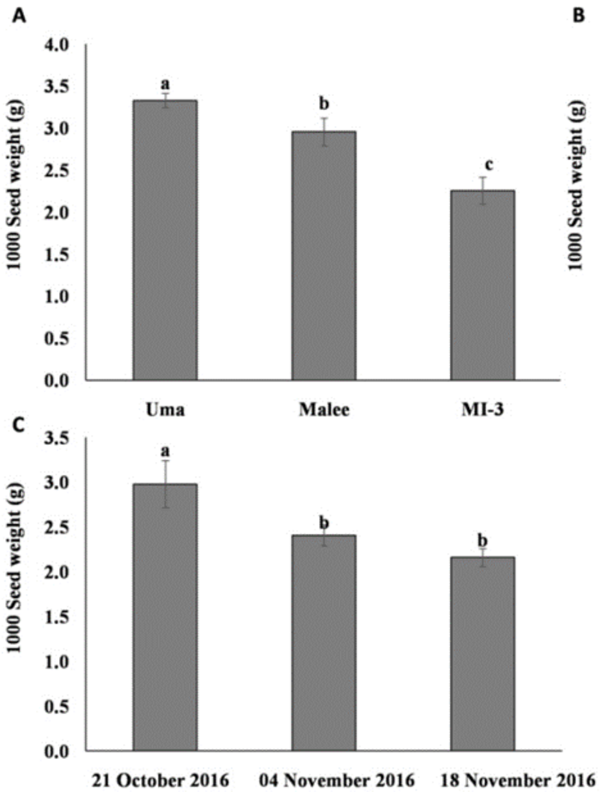


Figure 7: Dry weight of 1000 seeds as affected by (A) variety in *Yala* season in 2016 (B) variety in *Mala* season and (C) sowing date in *Maha* season 2016/2017. Ear bars indicate stand error of the means. Means with same letters are not significantly different at α=0.05 as Duncan Multiple Range Test

crops had higher utilization of thermal energy while delay in planting resulted in a decreased yield of short and long duration monsoon crops. Ali and Jan (2014) found that the early sowing date significantly lengthened the vegetative and reproductive phases, high vegetative growth and biological yield than the late sowing dates in Pakistan. According to the results of several studies, the early planting and mid-planting dates were more productive than later planting days for sesame. Further, the interaction between sowing dates and sesame genotypes was non-significant. It indicates that the productivity of sesame genotypes affect significantly as same as the sowing dates (Sawant *et al*. 2017; Sawant *et al*. 2019).

According to the results of the studies conducted in southeastern Nigeria found that the planting time had a significant effect on the growth and yield of sesame (Ogbonna and Umar-Shaba, 2012; Olowe, 2007) while the appropriate sowing time for sesame was during the later part of the rainy season. Furthermore, the plant height, number of leaves, stem circumference and the number of branches per plant decreased due to the late planting (Ogbonna and Umar-Shaba, 2012). Sesame sown in early July grew faster and produced significantly higher weight of capsules and seeds per plant. It also produced more number of capsules per plant and higher seed weight (Olowe, 2007). Early planting in the season significantly increased grain yield for all accessions (Ogbonna and Umar-Shaba, 2012; Olowe, 2007). It is recommended to plant sesame in early July to middle of the month to achieve sustainable yield in Nigeria (Olowe, 2007). Among climatic factors, rainfall seems to contribute more to changes in yield throughout planting dates (Ogbonna and Umar-Shaba, 2012; Olowe, 2007). Another experiment conducted in northern Sudan with the aim of evaluating growth and yield of some promising sesame genotypes under different planting dates in mid-June, early July, and mid-July found that the planting dates was significantly affected on different growth and phenological parameters. Further, the highest seed yield was recorded when sowing was done in early July (El-Mahdi, 2007).

CONCLUSION

According to the results, measured plant growth parameters had significant relationships with AGDD. Therefore, received AGDD would be significantly affected the plant growth. Also, plant height and the number of leaves could be accurately predicted by using the fitted non-linear regression models for tested varieties for tested sowing dates. var. Uma cultivated at the early sowing date recorded the lowest AGDD to shift from one phonological phase to another. It showed the fastest growth and development than other varieties and sowing dates. Therefore, Uma was the best variety among tested due to its great adaptation ability and significantly high growth and development. Therefore, cultivating Uma, early in the *Yala* season would be the best combination based on growth. Var. MI-3 showed some adaptation to the *Maha* season than the *Yala* season with regards to growth. Accordingly, it seems that var. Uma sowing in the early of the season is the best combination for sesame cultivation in the dry zone of Sri Lanka in both seasons. However, it is difficult to recommend var. Uma as an efficient variety when sowing early in the season since a single data set for each season is not sufficient for field research to give a solid recommendation.

AUTHOR CONTRIBUTION

HWKPK performed the experiments, analysed & interpreted data. WMNDG conceptualised & designed the study. HWKPK, WMNDG and KMCF contributed in drafting the manuscript. KMCF critically revised the manuscript.

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