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Yields of sesame vary dramatically under rain-fed conditions on marginal lands in Thailand

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Abstract

The objectives of this research were to evaluate grain yield, related traits and some agronomic performances of 15 sesame cultivars under rain-fed conditions on marginal land of Northeast in Thailand. The experiments were conducted at two locations; Maha Sarakham and Buriram provinces in Northeast Thailand during the summer of 2018. The fields were arranged in a RCBD with 4 replications and 15 sesame cultivars. Significant differences were observed for all traits at both locations except SPAD chlorophyll meter reading (SCMR) at 90 DAP in Maha Sarakham. Significant differences were found between locations for yield and some of the yield components. It appeared that pod/plant, plant height, number of branches, and plant biomass were the most important components attributing to yield. Harvest index was negatively correlated with yield. Heritability estimates were the highest for plant height (0.88), branches per plant (0.92), pod width (0.95), and pod length (0.89). At Maha Sarakahm, cv. UB3 had the greatest grain yield (1058.03 kg ha^{-1}), and was among the highest for number of branches/plant, plant height, and number of pods/plant, whereas KKU1 had the highest harvest index (43.62%). Mahasarakham60 had the highest SCMR value at 60 and 75 DAP and also total chlorophyll content at 60, 75 and 90 DAP. At Buriram cv. Buriram had the highest number of branches/plant, plant height, SCMR, total chlorophyll content, and number of capsules/plant, but did not have a high grain yield (334.44 kg ha^{-1}). UB1 had the highest grain yield (545.63 kg ha^{-1}) at Buriram. Environmental factors affected agronomic performances and grain yield in sesame grown under the rain-fed condition and marginal land in Thailand. If breeding under various environmental conditions, traits such as plant height and number of branches per plant would achieve the highest gains.

Keywords: sesame, agronomic traits, yield performance, SCMR, chlorophyll content, broad sense heritability.
Abbreviations: DAP_days after planting; DTF_days to flowering; SCMR_SPAD chlorophyll meter reading; HI_harvest index; RCBD_ randomized complete block design.

Introduction

Sesame (*Sesamum indicum* L.) belongs to the Pedaliaceae family, and Africa is considered its center of origin (Sousa et al., 2014). Sesame is the ninth most cultivated oilseed crop in the world and is grown in 69 countries, with global production estimated at 3.5 million tons of grain (Silva et al., 2011). It is well known as one of the oldest oil crops used by humans for thousands of years in such uses as edible oil, paste, cake and confectionary purposes (Weiss, 2000). It is an important oilseed crop due to the oil having high antioxidant properties, low cholesterol and high polyunsaturated fats (Weiss, 2000). The composition of the seed is 50-60% oil, 18-25% protein, and the rest carbohydrate and ash (Elleuch et al., 2007; El Khier et al., 2008). Generally, sesame grows under rain-fed conditions, from arid to semi-arid regions, where the pattern and amount of rainfall changes during its reproductive growth causing decreases in seed yield and quality (Jiang et al., 2009; Pathak et al., 2014). In Thailand, sesame is primarily grown under rain-fed conditions, and is considered as a second crop in multi-cropping systems. This crop is grown in North and Northeast Thailand after harvesting the main crop rice (October-December) or before planting rice (February to May) in an upland paddy field, without irrigation. Moreover, some areas used for rice production are low in soil fertility and suffer severe conditions such as drought that could reduce yields and agronomic performance of sesame. Compared to other crops, sesame has better drought tolerance except for sensitivity to drought during germination and seedling stages (Orruno and Morgan, 2007; Boureima et al., 2011). In Thailand, there are diverse sesame cultivars and each cultivar has a different yield response under various environments. There have been previous studies on yield performances and related traits of sesame in Thailand under rain-fed condition on fertile soil

(Kaenhom et al., 2014; Pangtaisong et al., 2007). However, studies on marginal land and soil low in fertility are lacking.
Therefore, the objectives of this study were to evaluate grain yield and agronomic performances of 15 sesame cultivars under the rain-fed condition on marginal land in Northeast Thailand.

Results

Agronomic performances:

There were significant differences among cultivars for all agronomic traits and between locations for all traits except pod length and pod weight/plant (Table 1). There was significant location by cultivar interactions for all traits, except pod length and pod width, so results will be presented for individual locations where a significant interaction was found. The average number of days to flowering (DTF) was greater at Maha Sarakham (56.4 d) than at Buriram (41.5 d). Cultivar Kanchanaburi did not flower at either location and may have been sensitive to day length. There were no statistical differences between the other cultivars for DTF at Maha Sarakham. At Buriram, cultivars UB3 and Buriram had the greatest DTF (46.3 and 46.0 d, respectively), while CM07 had the least (36.3 d; Table 2). The mean total plant biomass (dry matter) was greater at Maha Sarakham (34.2 g/plant) than at Buriram (21.6 g/plant). Among cultivars, UB1 had the greatest biomass at Mara Sarakham (69.6 g/plant), while CM53 had the least (16.0 g/plant). KKU2 had the greatest biomass at Buriram (46.7 g/plant; Table 2). Harvest index (HI), the percent of total biomass contained in the pods, was greater at Buriram (46.0%) than at Maha Sarakham (36.2%). Cultivar Mahasarakham60 had the greatest HI at Buriram and KKU3 had the lowest (56.2% and 30.3%, respectively). At Maha Sarakham, cultivars KKU1 and KU18 had the greatest harvest index (43.6% and 41.7%, respectively) and cultivar Buriram the least (28.8%; Table 2). The average grain yield at Maha Sarakham was greater than at Buriram (427 and 242 kg/ha, respectively). UB3 was the highest-yielding cultivar at Maha Sarakham (1065 kg/ha). UB1 was the highest-yielding cultivar at Buriram (545 kg/ha), but also yielded well at Maha Sarakham (709 kg/ha; Fig. 1).

Pod traits

The mean number of pods per plant was greater at Maha Sarakham (89.1 pods/plant) than at Buriram (28.8 pods/plant), but the mean total pod weight did not differ between locations. At Maha Sarakham UB3, UB1, and KKU2 showed the highest number of pods per plant (150.2, 141.0, and 130.4 pods/plant, respectively) (Table 3). UB1 had the greatest total pod weight (21.6 g/plant) at this location. At Buriram, cultivars KKU3 and Buriram had the greatest number of pods per plant (52.2 and 51.1 pods/plant, respectively), whereas KKU2 and Cplus2 had the highest pod dry weight per plant (21.6 and 19.9 g/plant, respectively). Individual pod weight was greater at Buriram (418 mg) than at Maha Sarakham (136 mg), but no significant cultivar differences were detectable at Maha Sarakham. At Buriram, KKU2 and Cplus2 had the highest mean pod weight (756 and 720 mg, respectively; Table 3). Pod length and pod width did not show a significant cultivar by location interaction, and there was no location effect for pod length (Table 1). Among cultivars, KU18 had the greatest pod length (29.2 mm), whereas KKU2 and UB3 had the greatest pod width (8.6 and 9.0 mm respectively; Table 3).

Plant height and branching over time

Plant height did not show a significant location effect and the interactions of location by cultivar and location by cultivar by DAP were not significant (Table 4). Thus, the results of plant height over time are averaged across the two locations in Table 5. At 45 DAP the photosensitive cultivar Kanchanaburi was the shortest (25.7 cm) but it was among the tallest cultivars by 90 DAP. Other tall cultivars included KKU3 (136.5 cm) and UB1 (135.1 cm). By 90 DAP, KKU1 and CM53 were the shortest cultivars (86.0 and 72.1 cm, respectively; Table 5),
Branch count showed a different pattern, with all factors and interactions being significant (Table 4). Overall, plants showed less branching at Buriram, but the mean number of branches steadily increased from 45 through 90 DAPS. At Maha Sarakham the mean number of branches peaked at 60 DAP and then remained unchanged (Table 6). In Maha Sarakham, cultivars Buriram, UB3, and KKU3 had the highest number of branches per plant at 60, 75, and 90 DAP. At the Buriram location, cultivar Buriram had the highest number of branches per plant at 45, 60, 75 and 90 DAP (3.2, 4.6, 5.5 and 5.5 branches, respectively; Table 6). The photosensitive cultivar Kanchanaburi did not branch at Buriram and had less than one branch per plant at Maha Sarakham.
Data from tables 3, 5 and 6 shows that number of pods/plant, pod dry weight per plant and plant height had the highest effects on yield (Figure 1). Pearson correlation coefficients for Maha Sarakham show that pods/plant, plant height and branches at 90D were the most highly correlated components to yield (Table 7). And though KKU1 had the highest HI (43.6%) followed by KU18 at Maha Sarakham, and Mahasarakham60 the highest HI at Burinam they were not the highest yielders (Figure 1). Combined over locations HI was negatively correlated with yield (Table 7).

Chlorophyll content and SPAD (SCMR) correlations:

The SPAD readings (SCMR) at days 60, and 75 DAP correlated better with chlorophyll readings than at SCMR and chlorophyll at 90 DAP (Table 5). SPAD readings are much quicker and would be the best method for evaluating chlorophyll production. SPAD readings and chlorophyll both declined at 90 days (Figures 2 and 3). However, it appeared that the differences in chlorophyll content did not have any direct effect on the yield or yield components across the cultivars. For example, Mahasarakham60 had the highest SPAD chlorophyll meter reading (SCMR) both at 60 and 75 DAP (56.58 and 58.88 respectively) and the highest total chlorophyll content across the dates of collection (11.061, 11.693 and 8.735 μg/cm^2 respectively) (data not shown).

Table 1. Analysis of variance (ANOVA) for agronomic traits of 14 sesame cultivars grown at two locations in Northeast Thailand.

		F value								
Effect	DF	Grain yield	HI	DTF	Pods/plant	Pod width	Pod length	Pod wt/plant	Pod weight	Biomass
Location (L)	1/6	153.4***	7.07*	149.2***	151.8***	11.7*	0.25	0.00	47.74***	146.8***
Cultivar (C)	13/78	345.6***	4.62***	2.16*	27.31***	18.32***	8.57***	3.27***	6.23***	23.53***
L × C	13/78	106.8***	2.77**	1.93*	12.51***	0.86	0.68	2.31*	6.33***	8.67***

Cultivar Kanchanaburi was not included in these analyses because it did not flower at either location. DF, degrees of freedom (numerator/denominator); HI, harvest index; DTF, days to flowering, * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$.

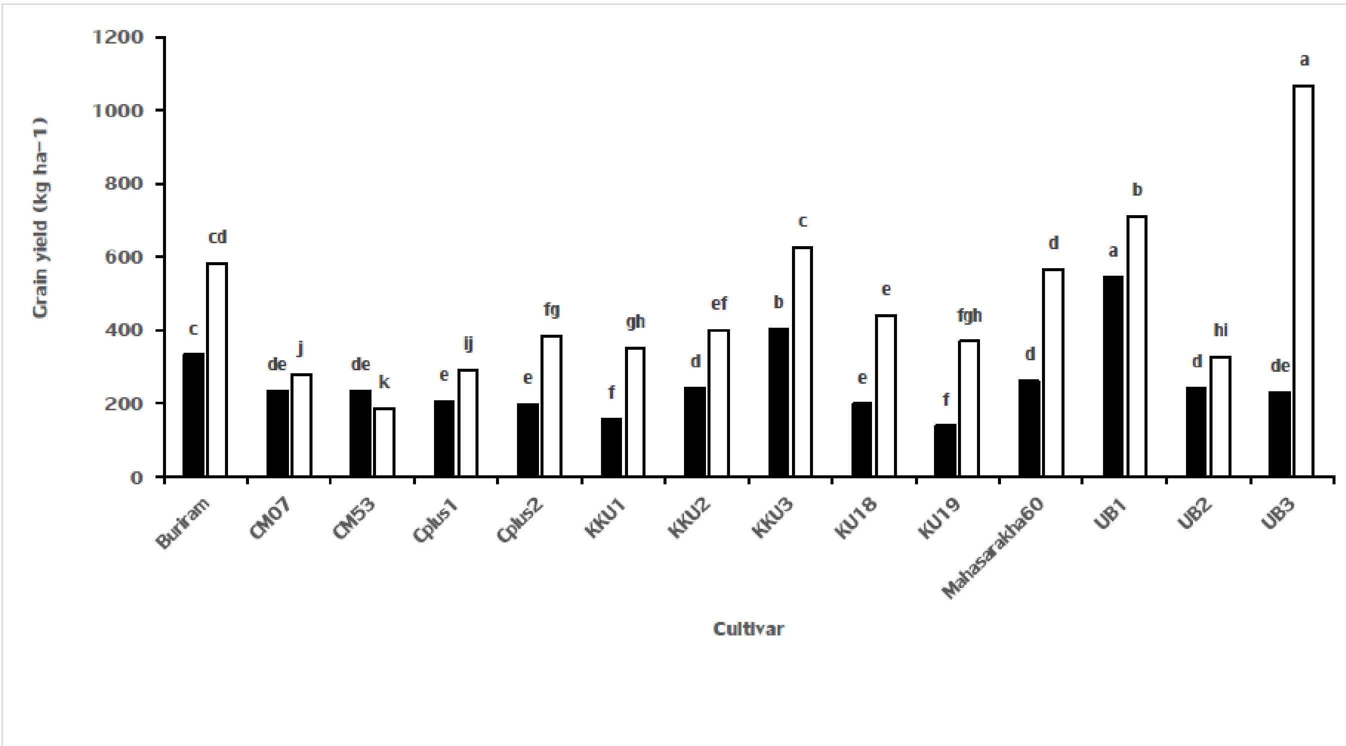

Fig 1. Grain yield of 14 sesame cultivars grown at Buriram (black bars) and Maha Sarakham (white bars) in Northeast Thailand in summer of 2018. Within locations, means with the same letter are not different at $P < 0.05$.

Table 2. Means of yield-related agronomic traits of 14 sesame cultivars grown at two locations in Northeast Thailand.

Cultivar	Days to flowering		Biomass (g/plant)		Harvest index (%)	
	Bur.	M.S.	Bur.	M.S.	Bur.	M.S.
Buriram	46.0 a	60.0	26.8 bc	42.3 bcd	48.7 ab	28.2 b
CM07	36.3 b	54.3	12.1 d	28.4 de	50.7 ab	38.2 ab
CM53	38.8 ab	59.3	17.0 cd	16.0 f	42.6 abc	35.7 ab
Cplus1	39.5 ab	61.3	18.6 cd	31.9 cd	48.7 ab	35.4 ab
Cplus2	39.0 ab	57.5	20.5 cd	28.7 de	46.0 ab	32.0 ab
KKU1	38.8 ab	57.3	18.8 cd	33.2 cd	44.6 ab	43.6 a
KKU2	41.5 ab	54.8	46.7 a	32.7 cd	48.2 ab	36.4 ab
KKU3	44.5 ab	57.3	26.1 bc	58.1 ab	30.3 c	32.3 ab
KU18	40.8 ab	51.8	13.4 d	46.4 bc	45.9 ab	41.7 a
KU19	41.8 ab	57.8	13.6 d	18.1 ef	54.1 ab	38.4 ab
Mahasarakha60	41.8 ab	54.8	25.7 bc	29.2 de	56.2 a	39.7 ab
UB1	42.0 ab	54.5	35.2 ab	69.6 a	42.0 bc	33.7 ab
UB2	43.8 ab	52.8	21.3 cd	36.6 cd	40.6 bc	37.9 ab
UB3	46.3 a	57.3	27.6 bc	42.9 bcd	47.2 ab	34.8 ab
Location mean	41.5	56.4	21.6	34.2	46.0	36.2

Bur., Buriram location; M.S., Maha Sarakham location. Within columns, means with the same letter are not different at $P < 0.05$.

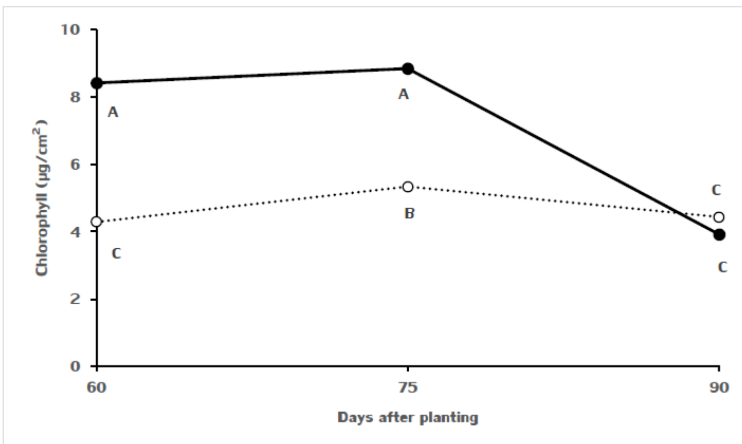

Fig 2. Mean leaf chlorophyll concentration over time of 15 sesame cultivars grown at Buriram (○) and Maha Sarakham (●) in Northeast Thailand in summer of 2018. Means with the same letter are not different at $P < 0.05$.

Heritability estimates:

For genetic improvements of crops it is common to estimate heritability of traits. The broad sense heritability of yield components of the sesame measured in this trial were estimated from the data. Grain yield had a heritability across locations of 0.51, which would indicate that genetic gains could be achieved quickly. However, plant height and branches/plant had much higher heritabilities (0.88 and 0.92 respectively) (Table 9).

Discussion

Many previous studies have reported on yield performance and agronomic traits of sesame (Baraki and Berhe,2019; Ofosuhene and Yeboah-Badu, 2010; dos Santos et al., 2018; Matusso and Faruque, 2015; Nadeem et al.,2015). However, this study is on yield of sesame under the rain-fed and marginal land conditions. Maha Sarakham has low soil fertility. Some of these same cultivars were tested under better field conditions in previous studies. Keitsakaret (2007) reported that cv. Mahasarakham, UB1, KU18, and KKU2 gave the high grain yield (552.0, 593.0, 686.7 and 669.3 kg ha^{-1}) which were slightly higher than our study. However, the number of pods per plant in our study was five times higher than their findings. Wongyai (2007) reported that cv. Cplus1 and Cplus2 had grain yields 1.5 t ha^{-1} which is five times greater than our study. Ogbonna and Ukaan (2012) reported that pod length ranged between 2.21-2.72 cm and capsule wide was 5.71-6.8 mm. Phusri et al. (1992) reported results from a planting date study for sesame cultivation. When Mahasarakham60 was planted from April to early May their highest grain yield (566.9-925 kg ha^{-1}) was higher than our study. When sesame was planted on Feb 22, Mar 10 and Mar 22 in Bangladesh plant height averaged lower than our study at both location and the number of pods/plant was 2-3 times lower than what we found (Sarkar et al. 2007). In another study, Roy et al. (2009) reported that there were significantly different grain yields on due to row spacing and were higher than our study. However, HI and number of pods/plant were lower than our study.

Table 3. Means of pod traits of 14 sesame cultivars grown at two locations in Northeast Thailand.

Cultivar	Pods/plant		Total pod weight (g/plant)		Pod weight (mg)		Pod width (mm)	Pod length (mm)
	Bur.	M.S.	Bur.	M.S.	Bur.	M.S.	C	C
Buriram	51.1 a	103.6 b	13.0 abc	11.9 ab	268 c	109	6.1 de	22.2 e
CM07	20.6 de	68.8 def	6.1 c	9.4 ab	293 bc	143	7.3 b	29.4 ab
CM53	20.4 de	72.8 cdef	6.5 bc	5.3 b	323 bc	68	7.2 bc	27.8 abcd
Cplus1	25.4 cde	67.2 ef	9.1 abc	10.2 ab	372 bc	148	7.2 b	27.8 abcd
Cplus2	27.5 cde	56.1 f	19.9 ab	9.2 ab	756 a	198	7.0 bcd	28.6 abc
KKU1	20.0 de	89.9 bcd	8.4 abc	12.8 ab	432 bc	165	5.9 e	24.1 de
KKU2	30.4 bcde	130.4 a	21.6 a	10.7 ab	720 a	86	8.6 a	25.5 cde
KKU3	52.2 a	89.4 bcd	13.5 abc	16.7 ab	262 c	181	6.2 cde	24.4 de
KU18	18.7 e	93.5 bc	6.6 bc	17.2 ab	354 bc	184	6.5 bcde	29.9 a
KU19	21.9 de	65.4 ef	9.1 abc	6.0 b	436 bc	91	7.1 bc	27.4 abcd
Mahasarakha60	37.6 abc	92.4 bc	14.3 abc	10.7 ab	419 bc	116	6.7 bcde	25.4 cde
UB1	44.1 ab	141.01 a	15.4 abc	21.6 a	355bc	155	6.6 bcde	24.9 cde
UB2	31.56 bcd	81.1 bcde	11.2 abc	12.4 ab	368 bc	162	6.9 bcd	26.0 bcd
UB3	25.9 cde	150.2 a	12.8 abc	13.6 ab	492 b	92	9.0 a	24.4 de
Location mean	28.8	89.1	12.0	12.0	418	136	-	-

Bur., Buriram location; M.S., Maha Sarakham location; C, locations combined. Within columns, means with the same letter are not different at $P < 0.05$.

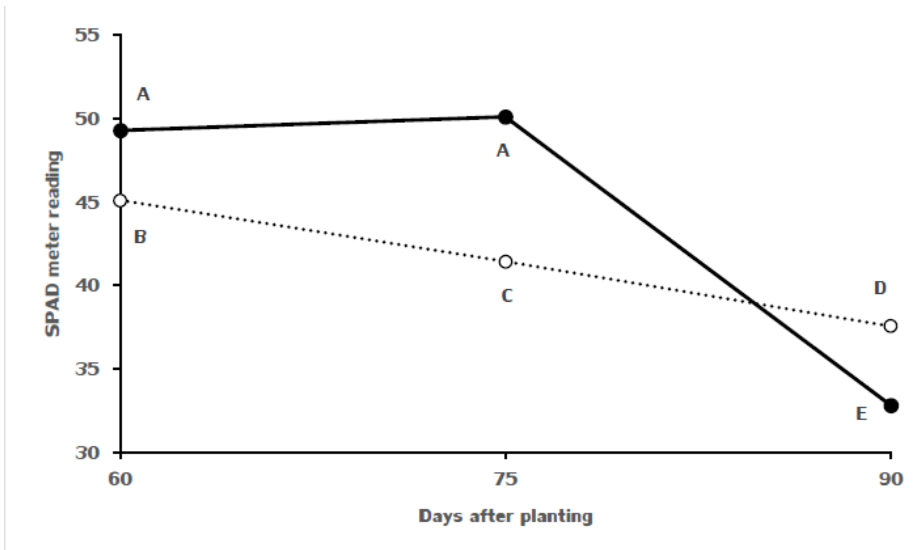

Fig. 3. Mean SPAD chlorophyll meter reading over time of 15 sesame cultivars grown at Buriram (○) and Maha Sarakham (●) in Northeast Thailand in summer of 2018. Means with the same letter are not different at $P < 0.05$.

Table 4. Analysis of variance (ANOVA) for time-dependent traits of 15 sesame cultivars grown at two locations in Northeast Thailand.

		F value	
Effect	DF	Height	Branches/plant
Location (L)	1/6	2.08	383.6***
Cultivar (C)	14/353	11.36***	57.62***
L × C	14/353	1.19	4.38***
DAP	3/353	895.4***	53.12***
L × DAP	3/353	51.77***	10.02***
C × DAP	42/353	4.53***	3.85***
L × C × DAP	42/353	1.38	2.01***
		F value	
Effect	DF	Total chlorophyll	SCMR
Location (L)	1/6	40.70 ***	13.00 *
Cultivar (C)	14/264	9.99 ***	6.20 ***
L × C	14/264	1.94 *	1.44
DAP	2/264	194.19 ***	175.2 ***
L × DAP	2/264	134.1 ***	47.36 ***
C × DAP	28/264	1.74 *	1.10
L × C × DAP	28/264	1.86 **	1.50

DF, degrees of freedom (numerator/denominator); DAP, days after planting; SCMR, SPAD chlorophyll meter reading; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

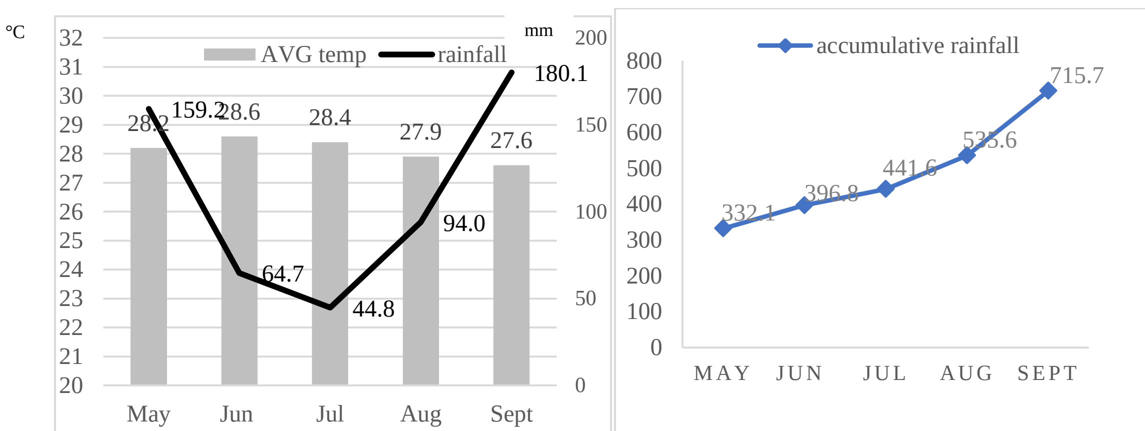

Fig 4. Average temperature, rainfall and accumulative rainfall of Buriram province during May to September 2018.

Table 5. Plant height over time of 15 sesame cultivars grown at two locations in Northeast Thailand (locations combined).

	Plant height (cm)			
Cultivar	45 DAP	60 DAP	75 DAP	90 DAP
Buriram	59.3 ab	99.7 abc	123.7 a	125.7 abc
CM07	58.3 ab	82.2 bcde	96.2 bc	101.5 cde
CM53	49.4 abc	59.5 e	70.0 d	72.1 f
Cplus1	41.5 abc	76.6 cde	94.3 bcd	103.4 bcde
Cplus2	46.9 abc	80.8 bcde	93.7 bcd	104.6 bcde
Kanchanaburi	25.7 c	60.2 e	89.8 bcd	105.9 bcde
KKU1	36.5 bc	68.1 de	78.0 cd	86.0 ef
KKU2	47.3 abc	92.6 abcd	114.0 ab	124.8 abc
KKU3	62.5 a	105.6 ab	129.9 a	136.5 a
KU18	56.1 ab	94.4 abc	105.7 ab	116.1 abcd
KU19	41.1 abc	79.5 cde	92.0 bcd	92.6 def
Mahasarakha60	52.5 ab	92.12 abcd	109.7 ab	113.6 abcd
UB1	58.3 ab	102.1 abc	123.8 a	135.1 a
UB2	53.8 ab	98.6 abc	115.3 ab	120.3 abc
UB3	48.7 abc	107.9 a	125.7 a	128.4 ab
Mean	49.2 D	86.7 C	104.1 B	111.1 A

DAP, days after planting. Within columns, means with the same lowercase letter are not different at $P < 0.05$. Means with the same capital letter are not different at $P < 0.05$.

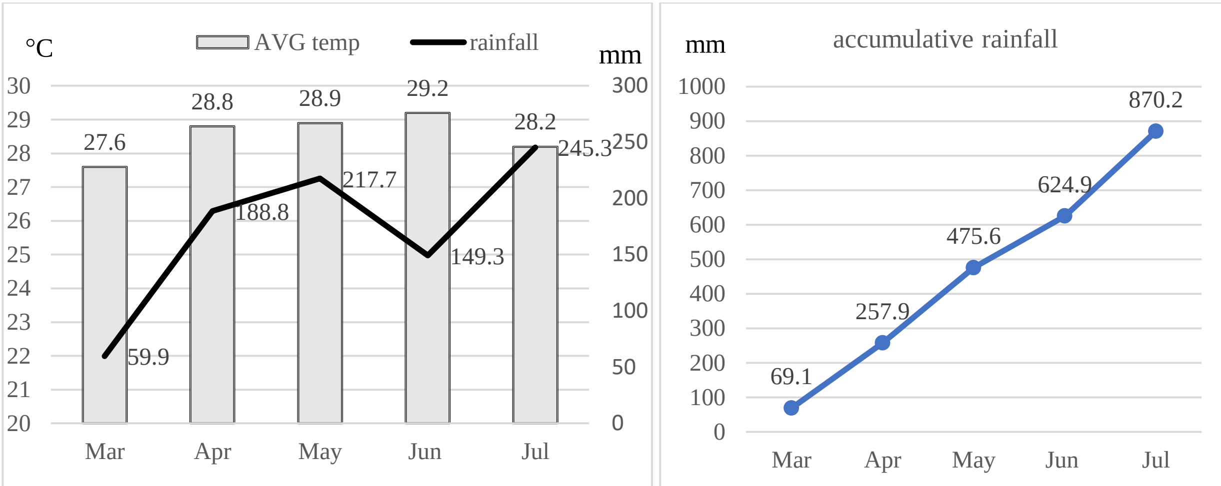

Fig 5. Average temperature, rainfall and accumulative rainfall of Maha Sarakham province from March to July 2018.

Table 6. Number of branches over time of 15 sesame cultivars grown at two locations (Buriram and Maha Sarakham) in Northeast Thailand.

Cultivar	Branches/plant							
	Buriram				Maha Sarakham			
	45 DAP	60 DAP	75 DAP	90 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Buriram	3.2 a	4.6 a	5.5 a	5.5 a	4.9 a	6.8 ab	7.0 a	6.7 a
CM07	2.0 abc	2.1 bcd	2.2 cd	2.3 cde	3.6 abcd	3.7 cde	3.2 def	3.6 def
CM53	1.8 abc	2.0 bcd	2.0 cde	2.1 cde	2.9 bcd	3.9 cde	3.4 def	4.1 de
Cplus1	1.2 bcd	1.5 bcde	2.2 cd	2.4 cd	2.7 cd	4.0 cde	4.2 de	4.1 de
Cplus2	0.8 cd	1.6 bcde	1.9 cde	2.3 cde	3.6 abcd	4.6 cd	4.6 bcde	4.0 de
Kanchanaburi	0.0 d	0.0 e	0.0 f	0.0 f	0.7 e	0.5 g	0.7 h	0.9 h
KKU1	0.3 cd	0.5 cde	0.6 def	1.0 def	2.6 cd	1.9 fg	1.4 gh	1.7 gh
KKU2	1.9 abc	2.7 b	2.7 bc	3.5 bc	3.3 abcd	4.9 c	4.8 bcd	4.7 bcd
KKU3	2.9 ab	2.9 ab	4.1 ab	4.4 ab	2.8 bcd	6.9 a	6.3 ab	6.3 ab
KU18	0.3 cd	0.4 de	0.4 ef	0.6 ef	3.0 bcd	3.1 def	3.0 efg	3.4 defg
KU19	1.7 abcd	1.8 bcd	1.7 cdef	1.8 cde	2.9 bcd	4.9 c	4.4 cde	4.4 cde
Mahasarakha60	0.4 cd	0.6 cde	0.6 def	0.9 def	2.1 de	2.4 ef	2.9 efg	2.8 efg
UB1	2.8 ab	3.2 ab	3.2 bc	3.1 bc	3.9 abc	5.1 bc	4.8 bcd	4.6 bcd
UB2	0.6 cd	0.8 cde	0.8 def	1.1 def	2.6 cd	2.8 ef	2.0 fgh	2.1 fgh
UB3	1.4 bcd	2.12 bc	2.1 cd	2.2 cde	4.5 ab	7.1 a	5.9 abc	5.9 abc
Mean	1.4 E	1.8 D	2.0 CD	2.2 C	3.0 B	4.2 A	3.9 A	3.9 A

DAP, days after planting. Within columns, means with the same lowercase letter are not different at $P < 0.05$. Means with the same capital letter are not different at $P < 0.05$.

Table 7. Correlations (Pearson's *r*) of agronomic traits with grain yield of sesame at Buriram, Maha Sarakham, and both locations combined.

Trait	Correlation (*r*) with grain yield		
	Buriram	Maha Sarakham	Combined
Harvest index	-0.322 *	-0.181 ns	-0.398 ***
Days to flowering	0.127 ns	-0.043 ns	0.421 ***
Pods/plant	0.702 ***	0.575 ***	0.706 ***
Pod width	-0.122 ns	0.279 *	0.242 *
Pod length	-0.178 ns	-0.399 **	-0.228 *
Pod weight/plant	0.195 ns	0.350 **	0.271 **
Pod weight	-0.324 *	0.057 ns	-0.410 ***
Biomass	0.445 ***	0.390 **	0.493 ***
Height at 90 DAP	0.449 **	0.561 ***	0.405 ***
Branches at 90 DAP	0.471 ***	0.469 ***	0.583 ***

DAP, days after planting; * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$; ns, not significant.

Table 8. Correlations (Pearson's *r*) of sesame leaf chlorophyll concentration with SPAD meter readings at 60, 75, and 90 days after planting (locations combined).

		Correlation (*r*) with SPAD meter reading		
DAP	Chlorophyll	60 DAP	75 DAP	90 DAP
60	Chl *a*	0.605 ***	0.630 ***	-0.066 ns
60	Chl *b*	0.571 ***	0.612 ***	0.060 ns
60	Chl total	0.614 ***	0.646 ***	-0.040 ns
75	Chl *a*	0.529 ***	0.771 ***	0.108 ns
75	Chl *b*	0.590 ***	0.767 ***	0.037 ns
75	Chl total	0.558 ***	0.785 ***	0.088 ns
90	Chl a	0.288 **	0.185 ns	0.387 ***
90	Chl b	0.388 ***	0.258 **	0.468 ***
90	Chl total	0.321 **	0.175 ns	0.466 ***

DAP, days after planting; ** $P < 0.01$, *** $P < 0.001$; ns, not significant.

Table 9. Variance components from the all-random model and heritability estimates for agronomic traits of sesame grown at two locations in Northeast Thailand.

Trait	σ^2_g	σ^2_{gl}	σ^2_e	h^2
Grain yield	10798	18353	8413	0.514
Harvest index	0.0007	0.0011	0.0039	0.391
Days to flowering	0.4402	3.6724	15.7232	0.104
Height at 90 DAP	314.75	14.66	274.50	0.883
Branches at 90 DAP	1.7006	0.1592	0.6342	0.915
Pods/plant	113.02	326.61	219.60	0.372
Pod width	0.7094	0.0000	0.3206	0.947
Pod length	0.0451	0.0000	0.0452	0.889
Pod weight/plant	4.2385	8.6369	30.1413	0.344
Pod weight	0	10276	7787	0.000
Biomass	57.97	18.58	287.74	0.562

σ^2_g, genotypic (cultivar) variance; σ^2_{gl}, genotype by location variance; σ^2_e, residual (error) variance, h^2, broad sense heritability; DAP, days after planting.

Table 10. Soil properties of two experimental sites in Northeast Thailand for the sesame cultivar trials planted in 2018.

Experimental site	Maha Sarakham	Buriram
pH	7.20	7.25
EC (µs/cm^2)	18	61.67
Organic matter (%)	0.412	0.615
Total N (%)	0.0215	0.034
Total P (mg/kg)	47.75	58.25
Total K (mg/kg)	97.95	172.58
Exchangeable Na (mg/kg)	13.59	21.09
Sand (%)	85	85.93
Silt (%)	7	11.93
Clay (%)	8	2.14
Soil Texture	Loamy sand	Sand

Planting dates were different at the two locations of our study. The Maha Sarakham location was planted almost two months earlier than the Buriram location. Also the meteorological data at the locations was different (i.e. monthly rainfall in Maha Sarakham was slightly higher than Buriram. Also, both locations have very low soil organic matter (<1%), the soil texture at Maha Sarakham was loamy sand whereas at Buriram was sand (Table 10). Therefore it was not surprising that our study showed lower grain yield than previously studied. However, both locations had sufficient P and K. The relationship between yield and yield components were as expected. Pod/plant, plant height, number of branches, and plant biomass all correlated with yield, but harvest index did not. Of these components plant height and number of branches per plant would be the ones to focus on for crop improvement as determined from the heritability estimates. The results of this study are important to growers to determine sesame cultivars to plant for high grain yield production in Northeast Thailand. Plant breeders could use this information to help determine the best methods for improving genotypes in marginal soils.

Material and methods

Plant materials

Fifteen sesame cultivars were obtained for use from Kasetsart University (KU18, KU19, CM07, CM53, Cplusl, Cplus2), Ubonrachathani University (UB1, UB2, UB3, Kanchanaburi), Khon Kaen University (KKU1, KKU2, KKU3), Kalasin University (Mahasarakham60), and Buriram was obtained from a farmer.

Layout

The experiment was laid out in a randomized complete block design (RCBD) with four replications and fifteen sesame cultivars. The experiment was conducted under the rain-fed conditions at two locations in Northeast Thailand (Maha Sarakham and Buriram provinces). In Maha Sarakham province the experiment was in a field of the Department of Agricultural Technology, Maha Sarakham University, Kantarawichai district) and planted on March 15, 2018. In Buriram, the experimental field was in an upland farmer field in Napho District, and planted on May 7, 2018. The spacing was 50 cm between rows and 20 cm between plants within rows. Each plot consisted of 4 rows that were 3.0 m long (12 m^2). The 15 cultivars were planted by hand and at 30 days after planting chemical fertilizer (formula 15-15-15 N,P,K) at a rate of 312.5 kg ha^{-1} was applied and weeding was done by hand. Irrigation was not used at either location.

Soil properties

The chemical content and texture were analyzed on soil samples from the 0–20 cm layer from both experimental areas. The soil pH was not different between locations, however the EC value on Buriram was slightly higher than at Maha Sarakham. Organic matter at both locations was very low. Total N, P, K and exchangeable Na at Buriram was higher than at Maha Sarakham. The soil texture at Maha Sarakam and Buriram were loamy sand and sand, respectively (Table 10).

Meteorological data

The average temperature, rainfall, and cumulative rainfall were monitored monthly (Figure 4 and 5). The average temperature from May to September in Buriram ranged between 27.6-28.6 °C and monthly rainfall 44.8-181.0 mm. The cumulative rainfall from January to September was 715.7 mm (Figure 4). In Maha Sarakham, the average temperature during March to July ranged between 27.6-29.2 °C and monthly rainfall 59.9-245.3 mm with cumulative rainfall from January to September 870.2 mm (Figure 5).

Data collection

The number of days to 50% of plants flowering (DTF) was recorded. Five plants from each plot were selected for data collection. The plant height and number of branches per plant were observed at 45, 60, 75, and 90 days after planting (DAP), SPAD chlorophyll meter reading (SCMR) and chlorophyll content recorded at 60, 75, and 90 DAP. The total dry matter (g per plant), pod dry weight (g per plant), number of capsules per plant, harvest index (HI), capsule width, capsule length, and grain yield were recorded at harvest. Grain yield was harvested from two rows within a four row plot. Plots were harvested by hand and sun dried after that threshing by hand.

The SCMR was measured by using a SPAD-502 meter (Minolta, Tokyo, Japan). The data points were recorded from 2 leaves per plot with one position along the length of the leaf blade (avoiding midribs) and then data points were averaged as a single value. The total chlorophyll content in leaves was measured by the method described by Moran (1982). Briefly, one small leaf disc per plot was cut with the area 1 cm^2 using a cork borer. The leaf disc was placed in a vial containing 5 ml DMF (N, N-dimethyl formamide) and incubated in 4 °C for 24 h in the dark. The chlorophyll extract was measured at 647 and 664 nm by a spectrophotometer (UV-1700 UV-visible spectrophotometer, Shimadzu). The equations to calculate total chlorophyll, chlorophyll a (Chl a) and b (Chl b) were as follows: Chl a = 12.64 A664-2.99 A647, Chl b= -5.6 A664+23.24 A647, expressed in µg cm^{-2}.

Statistical analyses

Data on grain yield, harvest index, days to flowering, biomass, and pod traits were analyzed by analysis of variance (ANOVA) using the GLIMMIX procedure in SAS v. 9.3 (SAS Institute, Cary, NC, USA). Location, cultivar, and their interaction were included as fixed effects, with replications (nested within location) as a random effect. Because of overdispersion, grain yield, biomass, and pods/plant were modeled using a Poisson distribution. Harvest index was modeled using a beta distribution. Because it did not flower at either location, cultivar Kanchanaburi was not included in these analyses. Data on time-dependent traits (plant height, number of branches, chlorophyll, and SPAD meter readings) were analyzed in GLIMMIX with location, cultivar, days after planting, and all possible interactions as fixed effects, and replications as a random effect. Repeated measures were modeled using a second RANDOM statement for DAP, with individual plots identified as subjects and a compound symmetric covariance structure. Kanchanaburi was included in analyses of time-dependent traits. All least squares means were separated using Tukey's HSD at α = 0.05 in the PLM procedure of SAS; all LS means are reported on the inverse-link (data) scale. Correlations were computed using the CORR procedure of SAS.

Heritability estimates were calculated for each trait using variance component estimates from an all-random model in GLIMMIX containing the factors location, cultivar, location × cultivar, and replication(location), and using the normal distribution for all traits. Heritability (broad sense, h^2) was calculated with the following formula:

$h^2 = \sigma^2_g / (\sigma^2_g + (\sigma^2_{gl}/l) + (\sigma^2_e/rl))$

where σ^2_g is the genotypic (cultivar) variance, σ^2_{gl} is the genotype by location variance, σ^2_e is the residual (error) variance, l is the number of locations (2), and r is the number of replications at each location (4).

Conclusions

This study on yield performance and related traits was done at two diverse locations on marginal land in Northeast Thailand. The environments of the diverse locations affected grain yield and agronomic traits attributing to yield of 14 sesame cultivars. In Maha Sarakham, UB3 had the highest grain yield and number of capsules per plant while UB1 had the highest grain yield and number of capsules per plant at Buriram. In both instances, the number of branches, plant height, and number of capsules per plant were all highly correlated with high grain yields.

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