Effects of ethephon on growth and yield of sweet sorghum (*Sorghum bicolor* L. Moench) at different growth stages

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Abstract

There is little information about the effects of ethephon ripening hormone on the yield of sweet sorghum in Thailand. Therefore, this study aimed to evaluate the impact of ethephon hormone applied at different growth stages of three cultivars of sweet sorghum on its growth and yield. The experiment was conducted from December 2016 to May 2017 at a research plot of the Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. The experiment was designed as a split-plot design with three replications. Three sweet sorghum cultivars (Ethanol 2, KKU 40, and Cowley) were planted in the main plot. Ethephon was applied at five stages of growth of these cultivars: heading stage, panicle stage, milking stage, dough stage, harvesting stage. Ethephon applications at those stages and untreated control were the subplots. Results showed that Ethanol 2 cultivar exhibited a higher growth rate, plant height, stem diameter, grain yield, stem fresh weight, and yield, juice extract yield, and sugar content than those exhibited by KKU 40 and Cowley. Application of ethephon at the heading stage gave the lowest stem diameter, grain yield, stem fresh weight, and yield, whereas applying it at the harvesting stage gave the highest sugar yield. There were no significant correlations between sweet sorghum cultivars and the growth stages at which ethephon was applied. Based on these results, it might be concluded that Ethanol 2 cultivar should be treated with ethephon hormone at its harvesting stage.

Keywords: sweet sorghum, growth, yield, ethephon, harvesting stage

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Introduction

Sweet sorghum (*Sorghum bicolor* L. Moench) or Sorgo is a grass family in the C_4 Graminaceous crop characterized by its high biomass and high sugar crop efficiency (Umakanth, 2014). The crop duration of sweet sorghum is short, about 4-5 months (Nimbkar et al., 2006). Sweet sorghum has several excellent characteristics such as water-lodging tolerance, salinity resistance (Regassa and Wortmann, 2014), drought resistance (Almodares et al., 2013), and thriving under hot and dry climatic condition (Almodares and Hatamipour, 2011a). Sweet sorghum accumulates carbohydrates as starch in its seeds or grains; hence the grains can be used as an animal feed or food; the stems can be used as

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a feed and can be processed to yield sugar, alcohol, and syrup (Regassa and Wortmann, 2014). Its bagasse can be used to produce paper and fuel. Juice extracted from fresh stems is composed of glucose, fructose, and sucrose (Ekefre et al., 2017), which can be readily fermented with yeast into alcohol. Juice extracted from the stalks contains a high concentration of soluble sugars (10–15%), i.e., the juice has a high Brix degree (Nimbkar et al., 2006). The height and stem diameter of the internodes of sweet sorghum contribute substantially to stem fresh yield. Previous studies on sweet sorghum were mostly on stem growth stage and sugar accumulation. A study in Thailand of twenty sweet sorghum cultivars found that their mean Brix degree (total soluble solids) was high in the range of 14–16% (Pothisoong and Jaisil, 2011). Sweet sorghum is genetically diverse; some provide high juice Brix; some provide high total stalk sugar yield, and some provide upper stem fresh yield. Sorghum at different growth stages offers different amounts of sugar in its stem. The concentration of stalk sugar varies with cultivar, and growth stage (Regassa and Wortmann, 2014).

There have been only a few studies in Thailand concerning the chemical ripening of sweet sorghum. Chemical ripeners (viz. Ethephon, Glyphosate, Trinexapac-ethyl, and sulfometuron-methyl) have been applied as a foliar spray on the crop with a foliar spray machine (Solomon and Li, 2004). Ethephon (2-chloroethyl phosphonic acid, Ethrel) is an essential plant growth regulator, and a chemical ripener (Li, 2004) used extensively for many kinds of the crop, including sugarcane, and sweet sorghum. Previously, it has been discovered that, in addition to its excellent ripening property, ethephon promoted sugarcane growth. Ethephon at a low concentration significantly improved sugarcane growth when it was sprayed on the leaves at the early growth stage (before the blooming stage) leading to an increase in stalk and sugar yield at the final harvesting stage (Li, 2004). Almodares et al. (2013) reported that applying 200 ppm Ethrel during the early tillering stage caused a significant decrease in the height of sugarcane plants but an increase in stem diameter and stem and sugar yields as well as the numbers of its tillers, stems, and milling stems.

Responses of sweet sorghum to a chemical ripener have been found to vary with the rate of the ripener application, sorghum cultivar, physiological stage of the crop at the time of application, type of ripener, and growth conditions (Usofzadeh et al., 2013). Growth inhibition and yield reduction after ethephon treatment at various rates and growth stages have also been reported (Earley and Slife, 1969). Ethephon may also cause a reduction in the photosynthetic rate of leaves, but this reduction is generally assumed to be less than the resultant decrease in the sink demand, thus overall, facilitating an increase in sugar storage (Van Heerden et al., 2013). Although numerous papers have reported the effects of Ethrel ripening hormone application on a wide range of crops, information on the growth and yield responses of sweet sorghum to this growth regulator has been lacking. Thus, this study aimed to investigate the effects of ethephon ripening hormone applied at various growth stages on the growth and yield of sweet sorghum.

Materials and Methods

Table 1
Characteristics of the regional climate

Month	Height T (°C)	Low T (°C)	Humidity (%)	Sunshine hours (hr)	Evaporation (mm)	Rainfall (mm)
December	31.65	23.28	58	6.21	3.85	0.00
January	31.70	23.95	61	5.75	3.71	7.10
February	33.46	23.22	57	7.86	4.68	0.20
March	33.95	26.19	66	7.95	5.15	59.50
April	35.07	27.02	64	7.54	5.38	1.80
May	33.97	26.55	72	4.96	4.29	197.70
Total	199.80	150.21	379	40.27	27.05	266.30
mean	33.30	25.03	63	7.71	4.51	44.38

T = temperature

A field experiment was conducted at the Experimental Farm of the Faculty of Agricultural Technology, King's Mongkut Institute of Technology Ladkrabang, Bangkok, Thailand (13° 72´ N and 100° 78´ E; elevation 1.5 m above mean sea level), from December 2016 to May 2017. The conditions during the probationary period are listed in Table 1.

Three cultivars (Ethanol 2, KKU 40 and Cowley) of commercial sweet sorghum were assigned to the main plot, and 2.50 liters per square meters of 400 ppm ethephon was familiarly applied on sweet sorghum at different growth stages (panicle stage, heading stage, milking stage, dough stage, harvesting stage, and untreated control) as sub-plots. The experiment was a split-plot in a randomized complete block design with four replicates. Seedlings were planted at a rate of 10 kg ha^{-1}. The width between any two rows of plants was 70 cm, and the spacing between plants in any row was 10 cm. A potassium fertilizer was applied at 70 kg ha^{-1}; a phosphorus fertilizer was applied at 70 kg ha^{-1}, and a urea fertilizer (urea) was used at 90 kg ha^{-1}. Carbofuran insecticide and Dithane fungicide were sprayed on the plants to protect them from pests and diseases.

Table 2 shows that the soil at the experimental site was the Bangkok series (soil survey division, 1972). It was clay, characterized (depth 10-30 cm) by a particle-size distribution of 62.68% sand, 36.70% silt and 0.62% clay. The soil was slightly acidic with a pH value of 5.0, electrical conductivity (EC) of 2.70 µS/cm, and the composition of organic matter of 2.54%. The mineral nutrients in the soil were the following: available phosphorus of 18.07 ppm, available potassium of 304.20 ppm, available iron of 170.85 ppm, available magnesium of 195.13 ppm, available zinc of 4.51 ppm, and available copper of 2.51 ppm. A furrow irrigation system was used for weekly irrigation. The plot size was 3.00 x 3.00 m^2.

Data were taken as follows. The number of days to 50% flowering was determined by monitoring the number of days from sowing to when 50% of sweet sorghum heads showed up in each plot (booting stage). Plant height, stem diameter, grain yield, stem fresh weight, stem fresh weight yield, juice extract yield, Brix degree, total sugar content, and ethanol yield were recorded at the maturity stage. The average plant height, from stem base to panicle tip, was an average of three plants (Tsuchihashi and Goto, 2005). The stem diameter at the middle third of the plant was recorded with a digital caliper. The grain yield from weighing all panicles by threshing at harvesting stage was recorded. The stem fresh weight and stem fresh weight yield were recorded after the leaves and panicles were removed. To measure the Juice yield, stems were crushed to extract their juice using a sugarcane crusher. The soluble solids concentration (juice Brix degree) was measured with a digital hand-held refractometer (Erickson et al., 2012). The total soluble sugar content (Liu et al., 2008) was estimated by using the following equation:

$$y = 0.8111x - 0.37285$$

where y and x are total soluble sugar content (%) and Brix of stem juice (%), respectively. The ethanol yield (Soleymani et al., 2013) was estimated by using the following formula:

Ethanol yield = Total sugar content (%) × fresh biomass (t/ha^{-1}) × 6.5 (Conversion factor for ethanol from sugar) × 0.85 (process efficiency for ethanol from sugar)] × 1.27 [Specific gravity of ethanol (g/ml^{-1})].

Statistical Analysis

Table 2
Soil composition of the experimental plot

Depth (cm)	Soil component (%)			T	pH	EC (µS/cm)	OM (%)	Available nutrient (ppm)					
	clay	silt	sand					P	K	Fe	Mn	Zn	Cu
0-10	1.52	31.28	67.20	Clay	4.00	2.60	1.37	74.90	366.60	116.45	422.87	1.41	1.54
10-30	0.62	36.70	62.68	Clay	5.00	2.70	2.54	18.07	304.20	170.85	195.13	4.51	2.51

T = Texture; EC = Electrical conductivity; OM = Organic Matter; P = Phosphorus; K = Potassium; ppm = parts per million data were analyzed by using ANOVA following the procedure for split-plot design. Least significant differences (LSD) were calculated at 0.05 significant level wherever the F-test result was significant. All statistical analyses were performed with a Statistical Analysis System (SAS) computer program (SAS Institute, 1999).

Results

The average number of days until 50% of flowering

Table 3 shows the significant differences between cultivars ($p < 0.05$), which were observed on the day of 50% of flowering. The Cowley cultivar (Table 5) recorded the latest day to 50% of flowering (68.51 days); 50% of the flowering day for KKU 40 was a little earlier (63.39 days) while that for Ethanol 2 was the earliest (58.58 days). The effects of ethephon on the day to 50% of flowering at each of the five growth stages were non-significantly different ($p < 0.05$). The heading growth assisted with ethephon was the latest at 66.77 days while it was the earliest at 61.72 days when ethephon was applied at the harvesting stage (Table 6). However, when ethephon was not applied at all (i.e., the control), the day of 50% of flowering was even earlier at 60.77 days.

Plant height

Table 3
Results of an analysis of variance of the number of days until 50% of flowering, plant height, stem diameter, grain yield, stem fresh weight, and stem fresh weight yield at the harvest time of sweet sorghum cultivars affected by ethephon applied at different growth stages

Source		Sum of squares					
	d.f.	NDF	PH	SD	GY	SFW	SFWY
Block	2	68.25^{ns}	318.14^{ns}	0.89^{ns}	3.10^{ns}	23,871.56^{ns}	3.51^{ns}
Cultivar (A)	2	444.02*	23,342.35*	163.10*	106.45*	95,958.38*	83.51*
Error a	4	60.36	1,262.53	4.52	5.50	4,542.73	5.17
Growth stage (B)	5	45.20^{ns}	4,843.39*	27.59*	273.08*	72,167.53*	27.66*
A*B	10	3.96^{ns}	148.08^{ns}	1.56^{ns}	20.74*	2,419.57^{ns}	0.14^{ns}
Error b	30	53.49	845.73	3.54	7.38	7,900.57	3.53
Total	53	59.18	1,951.71	11.43	38.40	16,601.54	8.31
C.V. (A) (%)		12.24	13.66	12.78	10.19	11.18	14.20
C.V. (B) (%)		11.52	11.18	10.13	11.80	14.75	11.74

NDF = number of days until 50% of flowering; PH = plant height; SD = stem diameter; GY = grain yield; SFW = stem fresh weight; SFWY = stem fresh weight yield
ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Table 4
Results of an analysis of variance of juice extract yield, Brix degree, total soluble sugar content, and ethanol yield at the harvest time of sweet sorghum cultivars affected by ethephon applied at different growth stages

Source		Sum of squares			
	d.f.	Juice extract yield	Brix degree	Total SSC	Ethanol Yield
Block	2	44,688.04^{ns}	4.79^{ns}	1.03^{ns}	19,629.61^{ns}
Cultivar (A)	2	907,148.82*	55.95*	36.81*	91,408.45*
Error a	4	18,831.92	3.20	2.10	1,061.95
Growth stage (B)	5	279,785.04*	50.62*	33.30*	28,986.65*
A*B	10	12,790.71^{ns}	0.64^{ns}	0.43^{ns}	894.23^{ns}
Error b	30	13,446.72	4.09	2.70	1,101.64
Total	53	73,759.16	9.75	6.33	7,797.15
C.V. (A) (%)		12.45	10.91	11.23	13.32
C.V. (B) (%)		10.52	12.35	12.71	13.57

EY= extract yield; SSC= soluble sugar content
ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Sweet sorghum cultivars significantly affected plant height at $p < 0.05$ (Table 3). Cultivar Ethanol 2 recorded the tallest plant height (296.94 cm), followed by KKU 40 and Cowley in this order. Table 6 suggests that the highest plant height was of the untreated plants (control, not treated with ethephon). Among the plants treated with ethephon, the maximum plant height was 274.71 cm of the plants treated with ethephon at the harvesting stage, and the minimum height was 229.28 cm of those sprayed with ethephon at the heading growth stage. However, the interaction between cultivar and application of ethephon at different growth stages was not significant.

Stem diameter

An ANOVA indicated significant differences ($p < 0.05$) between the stem diameters of the three sweet sorghum cultivars (Table 3). Ethanol 2 cultivar produced the highest stem diameter (21.24 mm), followed by KKU 40 (18.14 mm) and Cowley cultivar (15.22 mm) in this order (Table 5). Besides, the stem diameters were significantly different for plants sprayed with ethephon at different growth stages, $p < 0.05$ (Table 3). Among the treatment groups, the stem diameter was the largest (19.54 mm) for the plants sprayed with ethephon at the harvesting stage and the smallest (15.92 mm) for the plants sprayed with ethephon at the heading stage (Table 6). However, among all treatment and control groups, the stem diameter was the highest (20.63 mm) for the plants in the control group. The interaction between the cultivar and application of ethephon at different growth stages was non-significant at $p < 0.05$.

Table 5

Number of days until 50% of flowering, plant height (cm), stem diameter (mm), grain yield (g/plant^{-1}), stem fresh weight (g/plant^{-1}), and stem fresh weight yield (t/ha^{-1}) as affected by ethephon applied at different stages of growth

Source	NDF (days)	PH (cm)	SD (mm)	GY (g/plant^{-1})	SFW (g/plant^{-1})	SFWY (t/ha^{-1})
Cultivars						
Ethanol 2	58.58^{b}	296.94^{a}	21.24^{a}	25.48^{a}	677.76^{a}	18.17^{a}
KKU 40	63.39^{ab}	258.33^{b}	18.14^{b}	22.93^{b}	598.37^{b}	16.01^{b}
Cowley	68.51^{a}	224.98^{c}	15.22^{c}	20.62^{c}	531.92^{c}	13.86^{c}

NDF = number of days until 50% flowering; PH = plant height; SD = stem diameter; GY = grain yield; SFW = stem fresh weight; and SFWY = stem fresh weight yield

ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Table 6

Number of days until 50% flowering, plant height (cm), stem diameter (mm), grain yield (g/plant^{-1}), stem fresh weight (g/plant^{-1}), and stem fresh weight yield (t/ha^{-1}) as affected by the application of ethephon at different growth stages.

Source	NDF (days)	PH (cm)	SD (mm)	GY (g/plant^{-1})	SFW (g/plant^{-1})	SFWY (t/ha^{-1})
Growth stages:						
Heading stage	66.77	229.28^{d}	15.92^{d}	15.81^{d}	843^{e}	13.70^{d}
Panicle stage	65.35	243.24^{cd}	16.78^{cd}	18.53^{c}	967de	14.57^{cd}
Milking stage	63.67	252.32^{bcd}	17.73^{bc}	21.06^{c}	1,076^{cd}	15.58^{bc}
Dough stage	62.73	267.22^{abc}	18.60^{b}	24.92^{b}	1,174^{bc}	16.63^{b}
Harvesting stage	61.72	274.71^{ab}	19.54^{ab}	27.45^{b}	1,225^{ab}	17.09^{ab}
Untreated control	60.77	293.74^{a}	20.63^{a}	30.27^{a}	1,325^{a}	18.51^{a}

NDF = Number of days until 50% of flowering; PH = plant height; SD = stem diameter; GY = grain yield; SFW = stem fresh weight; and SFWY = stem fresh weight yield

ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Grain yield

Table 3 shows that cultivar significantly affected grain yield at $p < 0.05$. Ethanol 2 cultivar (25.48 g/plant^{-1}) provided the highest grain yield, followed by KKU 40 (22.93 g/plant^{-1}) and Cowley (20.62 g/plant^{-1}) in that order (Table 5). Besides, the application of ethephon at different growth stages significantly affected grain yield at $p < 0.05$. The grain yield (Table 6) was the highest (30.27 g/plant^{-1}) for the control group (untreated with ethephon), followed by application of ethephon at the harvesting stage (27.45 g/plant^{-1}), the dough stage (24.92 g/plant^{-1}), the milking stage (21.06 g/plant^{-1}), the panicle stage (18.53 g/plant^{-1}), and the heading stage (15.81 g/plant^{-1}), in that order. The interaction between cultivar and application of ethephon at different growth stages was significant.

Stem fresh weight

Sweet sorghum cultivar significantly affected stem fresh weight at $p < 0.05$ (Table 3). Ethanol 2 cultivar (Table 5) provided the highest stem fresh weight (677.76 g plant^{-1}), followed by KKU 40 (598.37 g plant^{-1}), and Cowley (531.92 g plant^{-1}) in that order. The stem fresh weight of plants applied with ethephon at different growth stages was significantly different at $p < 0.05$. Among the study groups, the stem fresh weight was the highest (1,325 g/plant^{-1}) for the control group, followed by application of ethephon at the harvesting stage (1,225 g/plant^{-1}), the dough stage (1,174 g/plant^{-1}), the milking stage (1,076 g/plant^{-1}), the panicle stage (967 g/plant^{-1}), and the heading stage (843 g plant^{-1}), in that order. The interaction between cultivar and application of ethephon at different growth stages was non-significant (Table 3).

Stem fresh weight yield

The mean values of stem fresh weight yield in the treatment and control groups were significantly different at $p < 0.05$. Concerning the effect of cultivar, Ethanol 2 produced the highest stem fresh weight yield (18.17 t ha^{-1}), followed by KKU 40 (16.01 t ha^{-1}) and Cowley (13.86 t ha^{-1}) in that order (Table 4). Concerning the effect of the application of ethephon at different growth stages, stem fresh weight yields were significantly different at $p < 0.05$. It was the highest (17.09 t ha^{-1}) when ethephon was applied at the harvesting stage, followed by the dough stage, and the panicle stage, in that order. Overall, stem fresh weight yield significantly increased with ethephon application.

Juice extract yield

The results of an ANOVA indicated significant differences in juice extract yield between cultivars at $p < 0.05$ (Table 4). Ethanol 2 recorded the highest juice extract yield (1,290 l ha^{-1}) while Cowley recorded the lowest (853 l ha^{-1}). The application of ethephon at different growth stages also significantly affected juice extract yield at $p < 0.05$. The maximum juice extract yield (1,225 l ha^{-1}) was from the plants applied with ethephon at the harvesting stage, whereas the minimum (967 l ha^{-1}) was observed when plants were treated with ethephon at the heading stage in Table 8.

Table 7
Juice extract yield, Brix degree (%), total soluble sugar content (%), and ethanol yield (l ha^{-1}) from the application of ethephon at different growth stages

Source	Juice extract yield (l ha^{-1})	Brix degree (%)	Total SSC (%)	Ethanol Yield (l ha^{-1})
Cultivars				
Ethanol 2	1,290^{a}	18.14^{a}	14.34^{a}	310^{a}
KKU 40	1,161^{b}	16.40^{b}	12.93^{b}	254^{b}
Cowley	853^{c}	14.61^{c}	11.48^{c}	169^{c}

SSC= soluble sugar content
ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Brix degree

The effect of sweet sorghum cultivar on Brix degree was significant at 5% level of confidence (Table 4). Ethanol 2 yielded the highest Brix degree (18.14%), followed by KKU 40 (16.40%) and Cowley (14.61%). Table 8 also shows that the Brix degree was significantly related to the application of ethephon at different growth stages at $p < 0.05$. The Brix degree was the highest (19.42%) when ethephon was applied at the harvesting stage, followed by those at the dough stage, the milking stage, the panicle stage, and the heading growth in that order. The Brix degree yielded by the plants without any application of ethephon (control) was the lowest (13.36%). There was no significant interaction between cultivar and application of ethephon at different growth stages.

Total soluble sugar content

The effect of sweet sorghum cultivar on total soluble sugar content was significant at 5% level of confidence (Table 4). The total soluble sugar content of Ethanol 2 cultivar was the highest (14.34%), followed by that of KKU 40 (12.93%) and Cowley (11.48%), in that order. The effect of the application of ethephon at different growth stages on total soluble sugar content was significant at 5 percent confidence level. It was the highest when ethephon was applied at the harvesting stage (15.37 %), followed by the dough stage, the milking stage, the panicle stage, and the heading stage, in that order. There was no significant interaction between cultivar and application of ethephon at different growth stages (Table 4).

Ethanol yield

The mean values of ethanol yield were significantly different at 5% confidence level among the three sweet sorghum cultivars. Ethanol 2 cultivar produced the highest Ethanol yield (310 l ha^{-1}), followed by KKU 40 (254 l ha^{-1}) and Cowley (169 l ha^{-1}), as shown in Table 7. The effect of the application of ethephon at different growth stages on ethanol yield was significant at 5 percent confidence level. It was the highest (321 l ha^{-1}) when ethephon was applied at the harvesting stage, followed by the dough stage, the milking stage, the panicle stage, and the heading stage, in that order. There was no significant interaction between cultivar and application of ethephon at different growth stages (Table 4).

Discussion

As far as the effect of cultivars on growth parameters, and sugar yield is concerned, Cardozo and Sentelhas (2013) have reported that genetic potential and environmental condition (such as soil moisture, solar radiation, high and low temperatures, fertilizers, irrigation, and sowing date) strongly affected sweet sorghum growth parameters and sugar yields. Their findings are in total agreement with ours since the cultivars that were tested in both studies were either the same or a hybrid of them. Along the same line, for sweet sorghum hybrids primarily grown in Thailand,

Table 8
Juice extract yield, Brix degree (%), total soluble sugar content (%), and ethanol yield (l ha^{-1}) from the application of ethephon at different growth stages

Source	Juice extract yield (l ha^{-1})	Brix degree (%)	Total SSC (%)	Ethanol Yield (l ha^{-1})
Growth stages:				
Heading stage	843^{e}	13.97^{d}	10.96^{d}	161.23^{e}
Panicle stage	967^{d}	16.11^{c}	12.70^{c}	207.64^{d}
Milking stage	$1,076^{cd}$	17.38^{bc}	13.73^{bc}	253.51^{c}
Dough stage	$1,174^{bc}$	18.08^{ab}	14.29^{ab}	286.66^{b}
Harvesting stage	$1,225^{ab}$	19.42^{a}	15.37^{a}	321.34^{a}
Untreated control	$1,325^{a}$	13.36^{d}	10.46^{d}	237.57^{cd}

SSC= soluble sugar content
ns, *, and ** values within a column followed by the same letter are not significantly different at $p < 0.05$ as indicated by the least significant difference (LSD) test.

Pothisoong and Jaisil (2011) reported that they produced a high stripped stem yield, grain yield, ethanol yield, and Brix degree (13.60-16.00%) with a high percentage of extracted stem juice, which are in good agreement with our findings. Shukla et al. (2017) reported that sugar accumulation in the stem and plant height increased as a result of cultivar selection, and genetic or physiological constraints, which agrees well with our findings. Our findings also agree well with the findings from Gutjahr et al. (2013) that genotype, internode length, and stem diameter of sweet sorghum determined its sugar yield. Shinde et al. (2012) and Gutjhar et al. (2013) reported high positive correlations between Brix degree, sugar content, stem production as well as sugar yield, and stem production as well as several growth parameters (plant height, stem diameter, and juice yield) in the same way that we found (see Tables 3 and 5).

Also, as far as the effect of ethephon application at different stages on growth parameters and sugar yield is concerned, our 50% flowering time findings agree well with the conclusion reported by Ockerby et al. (2001) that sorghum pollination was delayed with an application of ethephon. Wei et al. (2006) reported that a high concentration of ethephon inhibited photosynthesis and prolonged the vegetative growth period, which agrees well with our findings. In the same vein, Li and Solomon (2003), as well as Almodares et al. (2013), reported that a low concentration of ethephon sprayed on the leaves of sugarcane at the early growth stage inhibited several of its growth parameters and photosynthesis for a short time. Ethephon at 1,200 ppm provided the highest biological yield, and stalk yield of sweet sorghum (Li and Solomon, 2003; Almodares et al., 2013). Also, the application of ethephon increased the sucrose content of sugarcane (Clowes, 1980; Morgan, 2003; Liao et al, 2003). There is a positive relationship between biological yield, and Brix degree (Zhao et al., 2009). Almodares et al. (2011b) reported that the amount of sucrose percentage and Brix degree depended on the type of sweet sorghum and its lines. Thakare et al. (2005) reported that, with the application of ethephon, sweet sorghum grew well and produced high biological yield and amount of sugar in the stem. This study demonstrated that ethephon can increase the mean sugar content of three sorghum cultivars in Thailand (Tables 4 and 7). Along the same line, Usofzadeh et al. (2013) reported that the application of some ethephon can increase the sucrose content in the stem of many sweet sorghum cultivars. Also, the biological yield and stalk yield increased significantly with the application of a higher amount of ethephon. Yang (1986) reported that for sugarcane, aerial sprays of ethephon (2.0 l ha^{-1}) 42-70 days before harvest consistently increased the sucrose content in the juice extract yield with no adverse effect on the stalk height, and cane yield of the succeeding ratoon crop. For sugarcane, many research studies have established that Ethrel applied 70 to 84 days ahead of the maturity phase can increase the sugar content of the juice yield without affecting the growth of the plants. Rostron (1975;1977) indicated that Ethrel increased the sugar yield, and sugar quality of NCO 376 sugarcane cultivar and other varieties when the soil moisture was adequate, but the responsiveness to low juice purity was linked to ethephon (Rostron, 1977). Li (1990) Stated that foliar spray of 400 ppm Ethrel of sugarcane in October resulted in a significant increase in sugar content in the stalk and improved the juice yield. Rostron (1977) reported that ethephon increased the sugar content of only the upper shoots.

The interaction between cultivar and application of ethephon at different growth stages of the average number of days until 50% of flowering was non-significant (Mohammed, 2017) because sweet sorghum was sprayed with ethephon at the head stages of only one treatment. The interaction of sweet sorghum cultivars and application of ethephon at different growth stages non-significantly affected plant height at $p < 0.05$ because of spraying ethephon at all growth stages. Almodares et al., 2013 and Usofzadeh et al., 2013 reported that ethephon at head stages of only one spraying was non-significant on plant height of sweet sorghum. Sommart et al. (2013) and Mohammed (2017) found that the spraying ethephon has been disrupted by plant height of sweet sorghum. Mohammed (2017) reported that the interaction between two cultivars and application of ethephon at different stages significantly affected grain yield. It was found that the inhibition of flowering in sugarcane by ethephon increased sugar yield by 10%. The treatment did not transferred nutrients to flower and seed (Moore and Osgood, 1989).

This study shows that the application of ethephon at different growth stages can increase a varying amount of sugar content. The highest sugar content was achieved when ethephon was applied at the harvesting stage, followed by at the dough stage, the milking stage, the panicle stage, and the heading stage, in that order (Tables 4 and 8). Our recommendation to farmers is to spray ethephon at 400 ppm and before harvesting for better sorghum growth and sugar content. Moreover, Ethanol 2 cultivar is a good cultivar that is well adapted to the environmental conditions in Thailand.

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