International Journal of Agricultural Technology 2019 Vol. 15(6):1053-1062
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Influences of trinexapac-ethyl on development and sugar content of sorghum bicolor

Yoosukyingsataporn, S.* and Detpiratmongkol, S.

Department of Plant Production Technology, Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand.

Yoosukyingsataporn, S. and Detpiratmongkol, S. (2019). Influences of trinexapac-ethyl on development and sugar content of sorghum bicolor. International Journal of Agricultural Technology 15(6): 1053-1062.

Abstract Result showed that no-interactions among the cultivars. The different trinexapac-ethyl doses and different periods of pre-harvest weeks provided significantly different sweet sorghum growth and yield at the $p < 0.05$. The control treatment provided the highest growth but low sugar yield. The trinexapac-ethyl ripener affected the highest growth and sugar yield when applied at 0.05 ppm and 1 pre-harvest week. On the other hand, trinexapac-ethyl (0.20 ppm) level inhibited the growth of sweet sorghum when applied at 5 pre-harvest weeks. At 0.05 ppm dose and 1 pre-harvest week, the chemical ripener provided the tallest plant height, biggest stalk diameter, juice extract, and sugar yields. Based on these findings, we recommended to apply the trinexapac-ethyl at 0.05 ppm dose by spraying 1 week before harvest. The sweet sorghum variety is recommended to be KKU 40 cultivar.

Keywords: sweet sorghum, trinexapac-ethyl, yield, growth

Introduction

Biofuel production has derived from as sugar-cane, sugar beet, wheat, and sweet sorghum that becomes a new renewable production of energy from plant materials or organic matters, and an alternative to fossil fuel which is caused the global warming by increasing the amount of carbon dioxide in the atmosphere (Dar *et al.*, 2018). Sweet sorghum crop has been recommended for the production of ethanol which is mixed with oil into a gasoline product (Almodares and Hadi, 2009). Sweet sorghum adapts well to any global environments. It is grown fertilely in three continents: America, Africa, and Asia (Rao *et al.,* 2013). It is a short duration crop that can be harvested in about four months, whereas sugarcane is harvested in one year. Sweet sorghum is an industrial crop that can be grown with a lower cost than corn, wheat and sugar beet (Regassa and Wortmann, 2014 and Mathur *et al.*, 2017). Tew and Cobill (2006) reported that cultivars and days of harvest were correlated to total juice

***Corresponding Author:** Yoosukyingsataporn, S.; **Email:** teetechno30@gmail.com

extract yield and composition sugar yield of sweet sorghum. Sugar yield increased during its growth stage but decreased with limited soil water and crowded plant population (Dar *et al.* 2018). Good characteristics of sweet sorghum for energy production are Brix degree of 13–24%, sucrose content of 7.2–15.5%, total stalk sugar yield of 12.0 Mg ha^{-1}, stalk fresh yield of 24-120 Mg ha^{-1} and biomass yield of 36-140 t ha^{-1} (Regassa and Wortmann, 2014).

Chemical ripeners cause accumulation of sugar content in the internodes of sorghum and sugarcane at their pre-harvest stage after the ripeners were sprayed onto them (Dalley and Richard, 2010). Their primary purpose is for making sorghum or sugarcane get riped quickly, shortening the pre-harvesting stage duration (Faria *et al*., 2014). Trinexapac-ethyl ($C_{13}H_{16}O_5$) is a plant growth regulator commonly used for regulating the growth of cereal and horticultural crops. It is used as an anti-lodging agent for wheat and turf grasses (Matysiak, 2006) and for inhibiting vegetative growth of peanut, potato, and bean (Correia and Leite, 2012) as well as a chemical ripener for sugarcane (Spaunhorst *et al.*, 2019 and Van Heerden, 2014). In addition to these, trinexapac-ethyl is used for controlling the growth of grasses. In this regard, (Orgeron *et al*., 2013) Trinexapac-ethyl blocks gibberellin synthesis by inhibiting gibberellin acid 20 (GA_{20}) hydroxylation to gibberellin acid1(GA_1). After trinexapac-ethyl is sprayed on the leaves, 3β-hydroxylase enzyme in the plant's main biosynthesis pathway of GA_1 is inhibited (Rademacher, 2000). The outcome is that the sugar content of sugarcane crop increases. Van Heerden *et al.* (2015) found that trinexapac-ethyl could increase sugar yield but reduce internode elongation and leaf growth.

The objective of this study was to investigate the effects on growth, development and total sugar yield of two sweet sorghum cultivars at harvesting stage there after sprayed with trinexapae-ethyl at pre-harvesting times.

Materials and Methods

Study area description

The location of the study area was conducted at an experimental plot of the Faculty of Agricultural Technology, King's Mongkut Institute of Technology Ladkrabang, Thailand. The plot was located at13 ° 43′ 36.21″ N, 100 ° 46′ 48.454″ E and 1.50 m. above mean sea level in Bangkok, Thailand. The experiment was done from July to December 2017. The soil belongs to Bangkok series with clay texture and slightly acidic (pH 6.2) which shown (details are in Table 1). The experiment was performed as 3 factors factorial experiment in Randomized Complete Block Design (RCBD) with three replications. Factor A was two sweet sorghum cultivars; Factor B was four trinexapac-ethyl doses per square meter (0, 0.05, 0.10 and 0.20 ppm) and factor 3 was three application times (1, 3 and 5 pre-harvest weeks). The size of the sub-plots was 9 square meters.

Crop husbandry

Sorghum plants were grown with a row spacing of 60 cm and plant-to-plant spacing of 10 cm in moist soil. The seeds were placed at a depth of 25 mm from the soil surface, and the seed rate was 11 kg ha $^{-1}$. Fertilizer were used as the following: 46 kg ha^{-1} of urea, 42 kg ha^{-1}of triple superphosphate, and 42 kg ha^{-1} of potassium sulphate. Furrow irrigation was applied every three days during the experiment. A herbicide was used as needed (one kg ha^{-1}of Atrazine). An insecticide Carbosulfan was sprayed at 15 days after germination. The weather conditions during the experiment are presented in Figure 1. The maximum and minimum temperatures were 32.85 and 24.36 ℃, and the average amount of rainfall was 6.20 mm per month. The humidity and evaporation per month were 76.01 % and 3.98 mm, respectively.

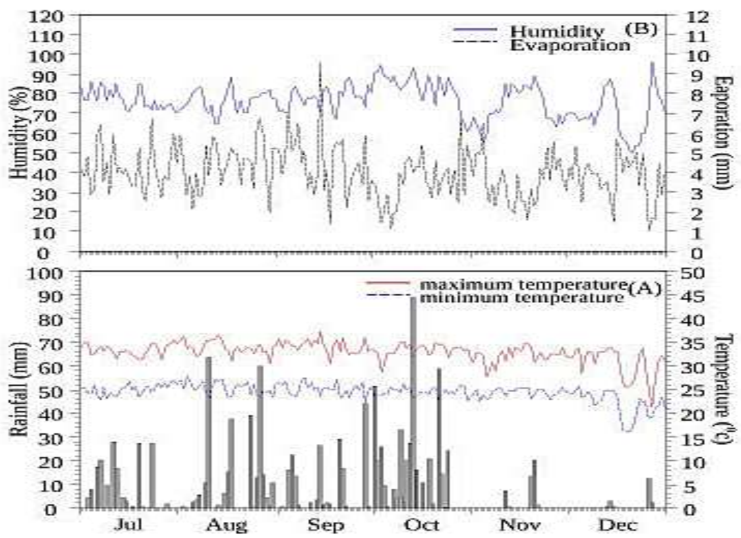

Figure 1. Weather conditions during the experiment: rainfall, maximum and minimum temperatures (A), and humidity and evaporation rate (B)

Table 1. Analysis of soil chemicals of Bangkok series soil

Depth (cm)	pH	EC (µS/cm)	OM (%)	Available nutrient (ppm)					
				P	K	Fe	Mn	Zn	Cu
0-30	6.2	2.60	1.95	46.49	335.40	143.65	309.00	2.96	2.03

Data collection

Growth parameter data were recorded at the harvest stage. The stem height of the sweet sorghum stem was measured from the ground to the distal by using the method of Shukla *et al*. (2017). A digital vernier caliper (Mitutoyo model: 500-196-30, Japan) was used to measure the diameter of sorghum stem according to the method of Tsuchihashi and Goto (2004). The number of internodes was counted for each internode from the ground to the top of the stem. A leaf area meter (Li-Cor model: Li 3000, USA) was used as a standard device for measuring leaf area. The biological yield was determined as the weight of dry stem samples. The juice was extracted by using a sugarcane juice machine (a motor-operated 3-roller press). Degrees of Brix was determined with a digital refractometer. Total soluble sugar content (Liua *et al*., 2008) was estimated based on the following equation: $y = 0.8111x - 0.37285$ (y = total soluble sugar content (%); x = Brix of stem juice (%)).

Statistical analyses

All collected data were statistically analyzed with a program called SAS v.9.2 for Windows. The growth and yield results were subjected to a three-way analysis of variance (ANOVA). The experimental design was a 2x4x3 factorial in RCBD, and means were compared by the Duncan's multiple range test (DMRT) at ($p < 0.05$).

Results

Plant height and Stem diameter

The plant heights and stem diameters of the two sweet sorghum cultivars were not significantly different ($p < 0.05$), but the plant heights and stem diameters of sorghum treated with different trinexapac-ethyl doses or different application times were significantly different ($p < 0.05$), as listed in table 2. A higher dose of trinexapac-ethyl (0.05-0.20 ppm) caused reduced plant height and stem diameter when compared to the control group (0 ppm), as listed in table 3. The application time at one week before harvesting provided the highest mean growth and stem diameter (268.58 cm and 22.39 mm, respectively), whereas the application time at three and five weeks before harvesting inhibited the growth of sweet sorghum, (253.08 cm and 18.54 mm, respectively, and 236.97 cm and 14.00 mm, respectively), as listed in table 3.

Table 2. Plant height, stem diameter, number of internodes, leaf area, biological and juice extract yield, Brix degrees, and total soluble sugar content of two sweet sorghum cultivars at the harvesting stage as affected by different trinexapac-ethyl application doses and application times

Source of variation	d.f.	Mean square							
		PH	SD	NI	LA	BY	JEY	Brix	Total SS
Block	2	29.32ns	0.12ns	3.76ns	32,338.74ns	97,532.11ns	69,202.89ns	1.16ns	0.76ns
Treatment	23	1,667.60*	53.75**	23.97**	2,336,678.83**	456,931.55**	779,817.24**	17.55**	11.55**
Cultivar (A)	1	897.82ns	13.40ns	9.03ns	224,595.15ns	321,785.05ns	150,883.55ns	3.22ns	2.12ns
Trinexapac-ethyl (B)	3	8,013.18*	117.84**	113.94**	5,569,913.29**	2,014,487.18**	2,816,184.00**	80.36**	52.88**
Pre-harvest weeks (C)	2	5,997.65*	422.29**	87.22**	16,340,996.27**	1,865,443.27**	3,930,410.88**	63.44**	41.74**
AxB	3	79.26ns	3.52ns	0.45ns	22,172.58ns	33,701.32ns	242,693.33ns	4.31ns	2.82ns
AxC	2	5.11ns	3.62ns	0.41ns	72,597.76ns	34,573.33ns	67,593.55ns	0.14ns	0.10ns
BxC	6	124.94ns	0.64ns	3.26ns	196,487.84ns	29,908.61ns	65,039.33ns	2.25ns	1.48ns
AxBxC	6	70.75ns	0.51ns	0.70ns	456,107.54ns	10,598.35ns	37,006.00ns	0.97ns	0.63ns
Error	46	693.43	4.45	3.41	108,056.13	102,500.50	92,715.24	2.84	1.87
Total	71	900.42	20.29	10.08	827,871.44	217,176.24	314,635.25	7.56	4.97
DMRT (0.05) (%) (A)		ns	ns	ns	ns	ns	ns	ns	ns
DMRT (0.05) (%) (B)		6.21	0.50	0.43	77.48	75.46	71.77	0.40	0.32
DMRT (0.05) (%) (C)		5.37	0.43	0.38	67.10	65.35	62.15	0.34	0.28
C.V. (%)		10.41	10.52	10.57	15.42	14.93	13.10	10.17	10.47

PH = plant height; SD = stem diameter; NI = number of internodes; LA = leaf area; BY = biological yield; JEY = juice extract yield; Brix = brix degree; and Total SS = total soluble sugar content.

ns = non-singnificant, * = significant at 0.05, and ** = significant at 0.01, respectively.

Means followed by different letters are statistically different according to Duncan's multiple range test (DMRT).

Table 3. Plant height, stem diameter, number of internodes, leaf area, biological and juice extract yield, Brix degrees, and total soluble sugar content of two sweet sorghum cultivars at the harvesting stage as affected by different trinexapac-ethyl application doses and application times

Treatments	**PH (cm)**	**SD (mm)**	**NI (internodes plant)**	**LA ($m\ m^{-2}$)**	**BY ($Kg\ rai^{-1}$)**	**JEY ($l\ rai^{-1}$)**	**Brix (%)**	**Total SS (%)**
Cultivars (A)								
KKU 40	256.41	18.74	17.83	2,187.98	2,210.74	2,369.89	16.77	13.23
Cowley	249.35	17.88	17.12	2,076.30	2,077.04	2,278.33	16.34	12.88
trinexapac-ethyl concentrations (B)								
0.00 ppm (control)	278.12A	20.85A	20.58A	2,834.64A	2,484.81A	2,783.77A	14.10D	11.06D
0.05 ppm	260.04B	19.19B	18.25B	2,301.05B	2,318.88A	2,499.78B	18.85A	14.92A
0.10 ppm	244.47BC	18.42B	16.33C	1,811.75C	2,052.96B	2119.11C	17.66B	13.95B
0.20 ppm	228.87C	14.79C	14.75D	1,581.10D	1,718.89C	1893.78D	15.63C	12.30C
pre-harvest weeks (C)								
1 week	268.58a	22.39a	19.37a	2,945.08a	2,419.72a	2,746.50a	18.09a	14.30a
3 weeks	253.08b	18.54b	17.50b	2,156.03b	2,149.72b	2,286.00b	16.74b	13.20b
5 weeks	236.97c	14.00c	15.56c	1295.30c	1,862.2c	1,939.83c	14.85c	11.67c

PH = plant height; SD = stem diameter; NI = number of internodes; LA = leaf area; BY = biological yield; JEY = juice extract yield; Brix = brix degree; and Total SS = total soluble sugar content.

Means followed by different letters are statistically different according to Duncan's multiple range test (DMRT).

Number of internodes and leaf area

Factor A (two sweet sorghum cultivars) did not significantly affect the number of internodes ($p < 0.05$), as listed in Table 2. Factor B (four different Trinexapac-ethyl concentrations doses) and Factor C (three different application times) significantly affect the number of internodes and leaf area ($p < 0.05$), as shown that in table 2. The number of internodes and leaf area of sweet sorghum grown normally in the control treatment was 20.58 internodes plant^{-1} and 2,834.64 mm^{-2}, respectively, whereas they were significantly lower in Factor B treatments (trinexapac-ethyl spraying at 0.05-0.20 ppm), as shown in Table 3. Similarly, Factor C treatments exhibited significant differences. The application time at one week before harvesting resulted in 9.37 internodes plant^{-1} and 2,945.08 mm^{-2} leaf area, while the application time at three weeks before harvesting resulted in 17.50 internodes plant^{-1} and 2,156.03 mm^{-2} leaf area, and the application time at five weeks before harvesting resulted in 15.56 internodes plant^{-1} and 1,295.30 mm^{-2} leaf area.

Biological and juice extract yields

Factor A (two sorghum cultivars) did not significantly affect the biological and juice extract yield ($p < 0.05$), whereas Factor B (four plant growth regulator doses) significantly affected them as well as Factor C (three different application times) as listed in Table 2. The biological and juice extract yields provided by the control were 2,484.81 Kg rai^{-1} and 2,783.77 l rai^{-1}, respectively, while those provided by and the plant growth regulator at 0.02 ppm were 1,718.89 Kg rai^{-1} and 1893.78 l rai^{-1}, respectively, as listed in Table 3. For Factor C (three different application times), the biological and juice extract yields were 2,419.72 Kg rai^{-1} and 2,746.50 l rai^{-1}, respectively, when the plant growth regulator was applied at one week before harvesting, 2,149.72 Kg rai^{-1} and 2,286.00 l rai^{-1}, respectively, when applied three weeks before harvesting, 1,862.20 Kg rai^{-1} and 1,939.83 l rai^{-1}, respectively, when applied five weeks before harvesting.

Brix degrees and total soluble sugar content

There were no significant differences ($p < 0.05$) in the Brix degrees and total soluble sugar content of the two sweet sorghum cultivars (Factor A), as listed in table 2, whereas applications of Factor B (four plant growth regulator doses) and C (three different application times) resulted in significant differences at $p < 0.05$. The Brix degree of sorghum in the control group was significantly lower than that in the group treated with trinexapac-ethyl at 0.05-

0.20 ppm, as listed in table 3. The Brix degree and total soluble sugar content of sweet sorghum applied with the plant growth regulator at one week before harvesting were 18.09 % and 14.30 %, respectively, at three weeks before harvesting was 16.74 % and 13.20 %, respectively, and at five weeks before harvesting were 14.85 % and 11.67 %, respectively.

Discussion

The growth parameters and sugar contents of sweet sorghum from treatments and control, were significantly differed. Those differences might come from the differences in the genes, breeding, and cultivars (Almodares and Hadi, 2009). That review paper stated that the aim of sweet sorghum development was to increase its growth parameter and sugar content with a focus on making it a feedstock for ethanol production. The effects investigated in the development were concerned the effect of crop management such as water (Yanaso and Detpiratmongkol, 2009), fertilizer (Almodares and Hoseini, 2016), and irrigation (Vannavong and Detpiratmongkol, 2008). The effect of weather such as temperature, day length, longitude, latitude, and elevation above mean sea level. The effect of crop systems such as crop rotation (Palumbo *et al*., 2014). It was found in this study that KKU 40 cultivar had better growth parameters (plant height, stem diameter, number of internodes, leaf area, biological and juice extract yield) and sugar content than Cowley cultivar, though not significantly ($p < 0.05$), which was not surprising because KKU 40 has been developed as a hybrid variety with good agronomic traits for planting in Thailand.

This study investigated applications of four different trinexapac-ethyl doses and three different application times harvesting that found the different doses, and provided significant differences in the development of stalk and internodes of sweet sorghum. Kingston and Rixon (2007) found that trinexapac-ethyl at 200 g ha^{-1} sprayed on sugarcane at 6-10 weeks before harvesting resulted in increased a higher sucrose level than that of the control, in agreement with the findings by Adams *et al*. (1991 and 1992) that the regulator reduced the length of internodes and stem. The plant growth regulator was also found to inhibit the growth of turfgrass compared to the control (Czeluściński *et al*., 2017). Furthermore, a study reported that trinexapac-ethyl at 200 g ha^{-1} provided a higher sucrose yield content than the control (Spaunhorst *et al*., 2019).

In this study, trinexapac-ethyl was found to decrease vegetative growth and increase sugar yield content. Application of the plant growth regulator at five weeks before harvesting inhibited cell division and vegetative growth (plant height, stem diameter, number of internodes, leaf area, biological and juice extract yield) because of increased gibberellin acid (GA_1), in agreement with the findings by Van Heerden *et al.* (2014). Increased GA_1 would be decreased cell volume, elongation of leaf cells, and shoot cell division cell of grasses crops (Van Heerden *et al*., 2014 and 2015). Application of the plant growth regulator at 0.05 ppm and one week before harvesting showed very effective at ripening sorghum, increasing juice sugar yield of up to 85% at harvesting (Resende *et al*., 2000).

Our recommendation to farmers is for them to spray trinexapac-ethyl at a 0.05 ppm dose and 1 week before harvesting for better sorghum growth and sugar content. Moreover, KKU 40 cultivar is a good cultivar that is well adapted to the environmental conditions in Thailand.

Acknowledgments

The authors would like to thank the Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, and the National Research Council of Thailand (NRCT), Bangkok, for providing financial support for this research.

References

Adams, R., Weiler, E. W., Kerber, E., Pfister, K. and Schar, H. P. (1991). Studies on the action of the new growth retardant CGA 163'935. Proceedings of the 14th International Conference on Plant Growth Substances, Amsterdam, pp.818-827.

Adams, R., Kerber, E., Pfister, K. and Weiler, E. W. (1992). Studies on the action of the new growth retardant CGA 163'935 (*Cimectacarb*). Progress in plant growth regulation: proceedings of the 14th International Conference on Plant Growth Substances, Amsterdam, Netherlands, pp.818-827.

Almodares, A. and Hadi, M. R. (2009). Production of bioethanol from sweet sorghum: A review. African Journal of Agricultural Research, 4:772-780.

Almodares, A. and Hoseini, S. H. (2016). Effect of sowing dates and nitrogen levels for ethanol production from sweet sorghum stalks and grains. African Journal of Agricultural Research, 11:266-275.

Correia, M. M. and Leite, G. J. (2012). Selectivity of the plant growth regulators trinexapac-ethyl and sulfometuron-methyl to cultivated species. Scientia Agricola, 69:194-200.

Czeluściński, W., Jankowski, K., Sosnowski, J. and Malinowska, E. (2017). Effects of trinexapac-ethyl on turfgrass growth and frequency of mowing Applied Ecology and Environmental Research, 15:739-746.

Dalley, C. D. and Richard, E. P. (2010). Herbicides as ripeners for sugarcane. Weed Science, 58:329-333.

Dar, R. A., Dar, E. A., Kaura, A. and Phutela, U. G. (2018). Sweet sorghum-a promising alternative feedstock for biofuel production. Renewable and Sustainable Energy Reviews, 82:4070-4090.

Faria, A. T., Silva, A. F., Ferreira, E. A., Rocha, P. R. R., Silva, D. V., Silva, A. A. and Tironi, S. P. (2014). Changes in physiological characteristics of sugarcane caused by trinexapac-ethyl. Revista Brasileira de Ciências Agrárias, 9:200-204.

Kingston, G. and Rixon, C. M. (2007). Ripening response of twelve sugarcane cultivars to Moddus® (trinexapac-ethyl). 8th Australian Society of Sugar Cane Technologists (ASSCT) Proceedings, Cairns, Queensland, Australian, 328-338.

Liua, R., Lib, J. and Shena, F. (2008). Refining bioethanol from stalk juice of sweet sorghum by immobilized yeast fermentation. Renewable energy, 33:1130-1135.

Mathur, S., Umakanth, A. V., Tonapi, V. A., Sharma, R. and Sharma, M. K. (2017). Sweet Sorghum as Biofuel Feedstock: Recent Advances and Available Resources. Biotechnology for Biofuels, 10:146.

Matysiak, K. (2006). Influence of trinexapac-ethyl on growth and development of winter wheat. Journal of Plant Protection Research, 46:133-143.

Orgeron, A. J., Griffin, J. L., Legendre, B. L. and Gravois, K. A. (2013). Influence of nitrogen fertilization on sugarcane response to the ripeners glyphosate and trinexapac-ethyl. Journal of the American Society of Sugar Cane Technologists, 33:30-37.

Palumbo, A. D., Vonella, A. V., Garofalo, P., Andrea, L. D. and Rinaldi, M. (2014). Response of a two-year sugar beet-sweet sorghum rotation to an agronomic management approach diversified by soil tillage and nitrogen fertilisation. Italian Journal of Agronomy, 9:109-114.

Rademacher, W. (2000). Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. Annual Review of Plant Physiology and Plant Molecular Biology, 51:501-531.

Rao, S. S., Patil, J. V., Prasad, P. V. V., Reddy, D. C. S., Mishra, J. S., Umakanth, A. V., Reddy, B. V. S. and Kumar, A. A. (2013). Sweet sorghum planting effects on stalk yield and sugar quality in semi-arid tropical environment. Agronomy Journal, 105:1458-1465.

Regassa, T. H. and Wortmann, C. S. (2014). Sweet sorghum as a bioenergy crop: Literature review Biomass and Bioenergy, 64:348-355.

Resende, P. A. P., Soares, J. E. and Hudetz, M. (2000). Moddus, a plant growth regulator and management tool for sugarcane in Brazil. Sugar Cane International, 4:5-9.

Shukla, S., Felderhoff, T. J., Saballos, A. and Vermerrisab, W. (2017). The relationship between plant height and sugar accumulation in the stems of sweet sorghum (*Sorghum bicolor* (L.) Moench). Field Crops Research, 203:181-191.

Spaunhorst, D. J., Todd, J. R. and Hale, A. L. (2019). Sugarcane cultivar response to glyphosate and trinexapac-ethyl ripeners in Louisiana. PLoS ONE, 14:e0218656.

Tew, T. L. and Cobill. R. (2006). Evaluation of sweet sorghum as a complementary bioenergy crop to sugarcane in Louisiana. Journal of American Society of Sugar Cane Technologists, 26:57-58.

Tsuchihashi, N. and Goto, Y. (2004). Cultivation of sweet Sorghum (*Sorghum bicolor* (L.) Moench) and determination of its harvest time to make use as the raw material for fermentation practiced during rainy season in dry land of Indonesia. Plant Production Science, 7:442-448.

Van Heerden, P. D. R. (2014). Evaluation of trinexapac-ethyl (Moddus) as a new chemical ripener for the South African sugarcane industry. Sugar Technol, 16:295-299.

Van Heerden, P. D. R., Mbath, T. P. and Ngxaliwea, S. (2015). Chemical ripening of sugarcane with trinexapac-ethyl (Moddus®) - Mode of action and comparative efficacy. Field Crops Research, 181:69-75.

Vannavong, W. and Detpiratmongkol, S. (2008). Effect of irrigation frequencies and water amounts on growth and yield of sweet sorghum. Proceedings of the 46th Kasetsart University Annual Conference, Subject: Plants, Kasetsart University, Bangkok, Thailand, pp.481-488.

Yanaso, P. and Detpiratmongkol, S. (2009). Effect of water deficit on growth and yield of sweet sorghum. Proceedings of the 47th Kasetsart University Annual Conference, Subject: Plants, Kasetsart University, Bangkok, Thailand, pp.465-472.

(Received: 31 July 2019, accepted: 31 October 2019)