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Assessment of agronomic performances and ethanol potential in diverse sweet sorghum (*Sorghum bicolor* L.) cultivars under rainfed conditions

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Abstract: Sweet sorghum has shown great potential as an alternative and promising bioenergy crop that has high potential for bioethanol production due to its high sugar yield, wide adaptability and drought tolerance, thus it is important to continuously evaluate and select most promising lines. Therefore, this study aimed to assess the agronomic performance, cane yield, and ethanol potential of local and exotic sweet sorghum cultivars under rainfed conditions. The experimental design was a randomized complete block design (RCBD) with three replications. Ten various sweet sorghum cultivars were utilized as treatments viz. Theis, Cowley, SSV74, SSV84, BJ248, Suwan sweet extra, Suwan sweet1 and 2, Suphanburi1 and KKU40 (check variety). The results indicated that several cultivars have noteworthy performances, exhibiting higher total soluble solids, such as cv. Suwan sweet extra, KKU40, Suwan sweet2, and Theis, as well as higher cane yield, including Cowley, SSV84, and Suwan sweet extra. Additionally, superior juice yield was observed in cv. SSV84, Suwan sweet1, Suwan sweet extra and Cowley, while higher theoretical ethanol yields were observed in cv. Suwan sweet extra, KKU40, SSV84, and Suwan sweet2. The consideration of grain yield revealed notable performances in cv. SSV84 and Cowley. Conclusively, both cv. SSV84 and Suwan sweet extra exhibited higher cane (46.72 and 44.03 t ha^{-1}, respectively) and ethanol yields (958.1 and 1155.7 l ha^{-1}) in alignment with the objectives of this study. Noteworthy traits were also identified in KKU40, Cowley, and Suwan sweet2. The findings from this study offer valuable insights for future research in this field, particularly in enhancing varietal performance in specific environments and promoting adaptability across diverse conditions.

Keywords: total soluble sugar, brix, cultivar evaluation, bioethanol, yield trial.

Abbreviations: cv_cultivar; RCBD_ramdomized complete block design; LSD_least significance difference; DAP_days after planting; HD_harvest day; SG_specific gravity; TEY_theoretical ethanol yield; RH_relative humidity; EC_electrical conductivity; OM_organic matter; M_mass; V_volume

Introduction

Sweet sorghum (*Sorghum bicolor* L. Moench), a C4 plant which exhibits high sugar content in its stalks similarly to sugarcane (Bunphan et al., 2014; Ratnavathi et al., 2011). Sweet sorghum belongs to the grass family, is recognized as a drought-tolerant crop and can be adapted to most of the temperate and tropical climates as an annual or short perennial crop (Khalil et al., 2015). It is extensively cultivated for food, feed, and fuel in the semiarid tropics of Asia, Africa, America and Australia (Kumar et al., 2011). Shukla et al. (2017) reported that sweet sorghum has potential as a multi-purpose crop whereby depending on the available infrastructure and market demands, all fermentable sugars from juice and biomass can be converted to renewable fuels and chemicals, or the juice can be processed to syrup, fuels or chemicals, while the bagasse is either burned or used as fodder.
Historically, sweet sorghum has been grown to support the production of syrup and molasses, but there is a growing interest in its use as a feedstock for renewable fuels and chemicals (Shukla et al., 2017). Sweet sorghum has gained considerable interest in recent years as a bioenergy crop due to its high biomass yield, fermentable sugar content (10-25%), resource use efficiency and drought tolerance (Nazli and Polat, 2024; Nazli, 2022; Almodares et al., 2007). There are approximately 4000 sweet sorghum cultivars distributed throughout the world (Rutto et al., 2013)
In Thailand, sweet sorghum is recognized as a promising alternative energy crop and fodder. Despite its potential, it remains a minor crop due to the lack of information and commercial cultivars. However, there has been notable research in this field, leading to the development and release of new cultivars. For example, cv. KKU40 was improved by Khon Kaen University, this cultivar was derived from cv. Keller using the pure line selection method (Postharvest Technology Innovation Center, 2008), cv. Suphanburi1 was improved at the Suphanburi Field Crop Research Center. This cultivar was developed using cv. M91019 as the female parent and cv. West African as the male parent (Suphanburi Field Crop Research Center, 2024). Additionally, Suwan sweet extra, Suwan sweet1, 2, 3, 4, and 5 were enhanced through research conducted at the Corn and

Sorghum Research Station of Kasetsart University. Even though there are several cultivars available in the country, it is important to evaluate and compare them with other commercial cultivars from around the world. This will help in assessing the local cultivar potential of competing with foreign ones for commercial cultivation. Therefore, this study aimed to assess the agronomic performance, cane yield, and ethanol potential of local and exotic sweet sorghum cultivars under rainfed conditions, building on the existing knowledge of sweet sorghum varieties worldwide.

Results and discussion

Analysis of variance

Pure-line sweet sorghum cultivars were collected from various regions worldwide, including the United States, China, India, and Thailand. These cultivars, which have been utilized for commercial production in their respective countries of origin, underwent evaluation under low-fertility conditions in Thailand, specifically in rainfed environments.

The study evaluated 10 different sweet sorghum cultivars, including one check variety, for agronomic traits, ethanol yield, and yield-related traits. The results showed significant differences in all traits except plant height at 60 and 75 DAP, number of leaves per plant at 75 DAP and at harvest, SCMR, and SG. The analysis of variance indicated significant differences in all traits studied, as reported in Table 1 and 2.

Agronomic performances

Days to 50% flowering: this is an important trait that is related to harvest day, as maturity is determined by number of days after 50% flowering of sweet sorghum. Days to 50% flowering was significantly different ($p \le 0.05$) among cultivars, ranging between 55.7-64.7 days, with cv. Theis having the shortest number of days to 50% flowering (55.7 days), whereas cv. Suwan sweet2 had the longest (64.7 days) however it was not significantly different from other cultivars i.e. KKU40, Suwan sweet extra, Suwan sweet1, SSV74, Cowley and BJ248 (Fig. 1). Oyier et al. (2017) and Mohammed and Abdalbagi (2021) also reported significant difference in this trait among cultivars studied, but the current results contrasted with Bunphan et al. (2014) who reported that days to 50% flowering did not differ among cultivars. Moreover, in other studies, days to flowering ranged between 58 to 100 days under well-water condition (Alhajturki et al., 2012), 65 to 96 days (Pedersen et al., 2012) and 57 to 113 days (Ali et al., 2008), 57 to 82 days (Oyier et al., 2017). Because sweet sorghum is a short-day plant, the timing of planting significantly impacts the number of days it takes to reach 50% flowering. Longer days to 50% flowering relate to longer vegetative phase and it has effect to reproductive, grain filling phase including stalk and grain yield. Therefore, the results suggest that sweet sorghum is more suitable for planting in the summer or rainy season, as it yields higher cane production compared to planting in the autumn or winter. This finding aligns with Rao et al. (2013), who reported that planting in early to mid-June (summer) resulted in higher stalk and grain yields compared to later planting dates. Similarly, Rongrit et al. (2011) observed that growing sweet sorghum from March to July (summer) achieved higher stalk yields than other planting seasons.

Plant height: these results revealed that plant height at 60 and 75 DAP were significantly different among cultivars; further significant differences were observed on this trait at harvest day with a range between 249.3-315.0 cm (Fig. 2). These results are similar to previous study which observed significant differences on this trait, Bunphan et al. (2014) who observed great variation in plant height among the studied genotypes. In contrast, Ekefre et al. (2017) reported no significant differences in plant height among genotypes recording height range of 259-270 cm, where cv. Theis in their study was 270 cm tall being taller than the

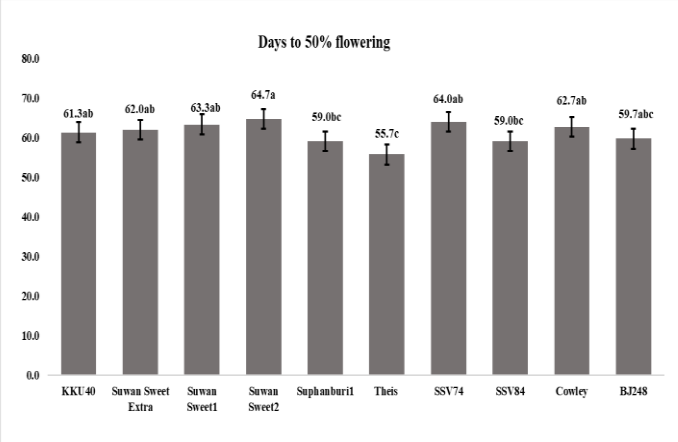

Fig. 1 Days to 50% flowering of ten sweet sorghum cultivars.

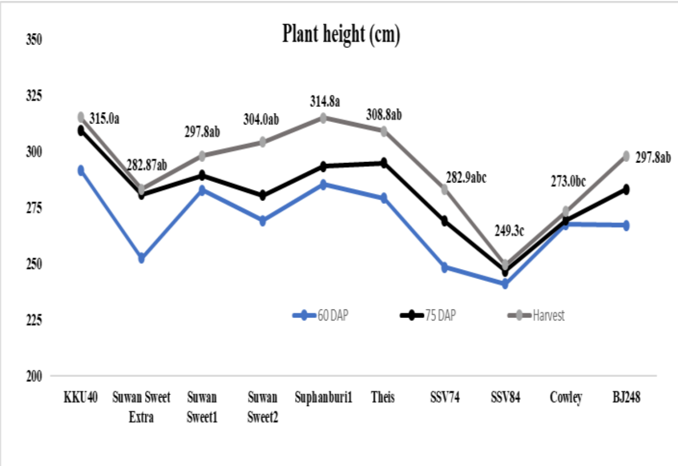

Fig. 2 Plant height at 60 75 DAP and harvest day of ten sweet sorghum cultivars.

height of same cultivar in our current study, whereas a recent report by Chaithrashree et al. (2024) recorded a height of cv. Theis at 308.8 cm and observed significant difference in plant height at all stages. These results showed shorter plant height compared to a recent study, which recorded height of 282.9 cm and 249.3 cm, respectively. Therefore, the same variety of sweet sorghum, even when grown in different environmental conditions, may exhibit variations in its characteristics. Previous studies had shown that plant height was positively correlated to strip stalk yield and biomass yield (Bunphan et al., 2014) whereas Bobade et al. (2019) did not find this association and range between 252.25-340.75 cm which was higher that a current report (Oktem and Oktem, 2022) and different among cultivars and across locations (Rono et al., 2016), differed among cultivars across three years in Mediterranean environment (Fracasso et al., 2017).

Stalk diameter: this trait recorded a significant difference ($p \le 0.05$) among cultivars at all stages. The cultivar SSV84 had a higher stalk diameter at 60, 75 DAP and harvest day (17.60 19.43 and 20.02 mm, respectively), however it did not significantly differ with cv. Cowley (15.85, 16.87 and 17.47 mm, respectively), whereas cv. Theis recorded smallest stalk diameter (Fig. 3). Ekefre et al. (2017) also reported that there were significant differences at all stages (85, 99 and 113 DAP) and cv. Theis in their study showed a higher stalk diameter, but in the current study the same cultivar recorded the smallest stalk diameter. Chaithrashree et al. (2024) found significant differences in this trait, with values ranging from 6.16 to 37.79 mm, their research included the cultivars SSV74 and SSV84 and their stalk diameter were different from the ones recorded in the current study. This indicates that the same cultivar, when planted in different environments or even in similar environments but different

Table 1. Analysis of variance (mean square) for some agronomic characteristics of ten various sweet sorghum cultivars.

SOV	df	Days to 50% flowrering	Plant height (cm)			Stalk diameter (mm)			Number of leaves per plant		
			60 DAP	75 DAP	HD	60 DAP	75 DAP	HD	60 DAP	75 DAP	HD
Block	2	69.0	10902.7	8871.5	2089.0	103.8	74.0	15.4	0.4	0.7	0.3
Cultivar	9	23.3*	855.2ns	892.7ns	1258.9*	13.7*	13.9**	10.1*	2.3**	1.1ns	2.1ns
Error	18	9.2	765.2	645.6	458.3	3.9	3.3	3.3	0.4	0.4	1.6
Total	29										

ns, * and **; non-significant, significant at p≤ 0.05 and 0.01 probability levels, respectively. HD, harvest day.

Table 2. Analysis of variance (mean square) for SCMR, yield and ethanol yield of ten various sweet sorghum cultivars.

SOV	df	SCMR			TSS	Stripped stalk yield	Juice yield	SG	Percent of ethanol	Grain yield
		60 DAP	75 DAP	HD						
Block	2	16.9	25.2	74.6	1.0	131.7	9.9	7.7	1.3	2.8
Cultivar	9	18.2ns	25.5ns	33.5ns	11.6**	442.6**	8.1**	4.8ns	5.4*	23.7**
Error	18	35.0	17.4	28.4	2.9	52.4	0.5	2.2	1.3	0.9
Total	29									

ns, * and **; non-significant, significant at p≤ 0.05 and 0.01 probability levels, respectively. TSS, total soluble solids, SG, specific gravity.

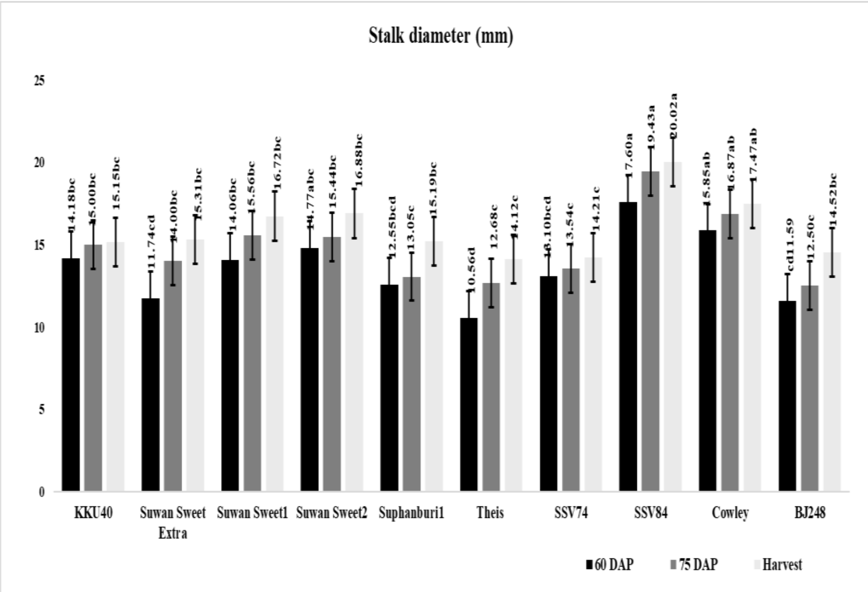

Fig. 3 Stalk diameter at 60 75 DAP and harvest day of ten sweet sorghum cultivars.

seasons or years, can exhibit varying performances in sweet sorghum. Oyier et al. (2017) similarly observed a significant difference on this trait, however their study, stalk diameter did not vary significantly among stages (p>0.05), this is in contrast

with findings with recent study that observed differences in stalk diameter across different growth. Contrary to Bunphan et al. (2014) findings, which indicated nonsignificant differences among cultivars with stalk diameter ranging from 10.62 to 12.63 mm, the recant study observed larger stalk diameter specially, cv. Cowley exhibited a greater stalk diameter in both reports, however, cv. SSV84 did not show a larger stalk diameter between cv. SSV74 and Suwan sweet extra did not differ under both well-watered and drought conditions. Oktem and Oktem (2022) reported that stalk diameter ranged between 19.15-25.60 mm, it was higher than a recent result (14.12-20.02 mm).

Number of leaves per plant: this trait was not significantly different at 75 DAP and harvest day (p≥0.05) but was significantly different at 60 DAP (p≤0.01) (Fig. 4). It ranged between 6.4-8.9 leaves, with cv. SSV84, KKU40, Cowley and SSV74 recording higher number of leaves than other cultivars, however at 75 and harvest day they there was no significant difference on number of leaves among cultivars (Fig. 4). The number of leaves in all cultivars exhibited a decrease towards harvest day as the plants transitioned to the senescence stage. Ekefre et al. (2017) found significant differences in number of leaves among cultivars, with a range of 13-16 leaves which was higher than values of the recent study. Da Silva et al. (2018) also reported a significant difference in the number of leaves among cultivars on harvest day, whereas in the current study there was no significant difference at that stage. The number of leaves exhibited a range between 7.08 and 7.57, additionally, there was a discernible decrease in the number of leaves as sweet sorghum aged, specifically between 45 and 90 days after planting (DAP) (Da Silva et al., 2018). Naoura et al. (2019) similarly found a significant difference in number of leaves, it ranged from 2.6-10.6 leaves. The number of leaves per plant has been associated with various growth parameters including crop growth rate (CGR) (r=0.661*), leaf area index (LAI) (r=0.608*), specific leaf weight (SLW) (r=0.774*) and yield per plant (r=0.719**) (Bobade et al., 2019), this association serves as a rationale for the observation of this trait.

Spad chlorophyll meter reading (SCMR): is a trait associated with chlorophyll content in sweet sorghum (Bunphan et al., 2018) and sugarcane (Bunphan et al., 2019). In a current study, SCMR did not exhibit any significant difference at any of the stages (Fig. 5). In contrast to Da Silva et al. (2018) and Bunphan et al. (2022) who found a significant difference in SCMR among two sweet sorghum cultivars, whereas Bunphan et al. (2018), found a significant difference in SCMR among genotypes and locations, Devkumar et al. (2014) reported a significant difference in SCMR among sweet sorghum cultivars at both 15 and 30 DAP. However, the present study measured SCMR at the reproductive stage and physiological maturity stage. Moreover, Oyier et al. (2017) who found a significant difference in chlorophyll content among sweet sorghum genotypes, growth stage and genotype ×

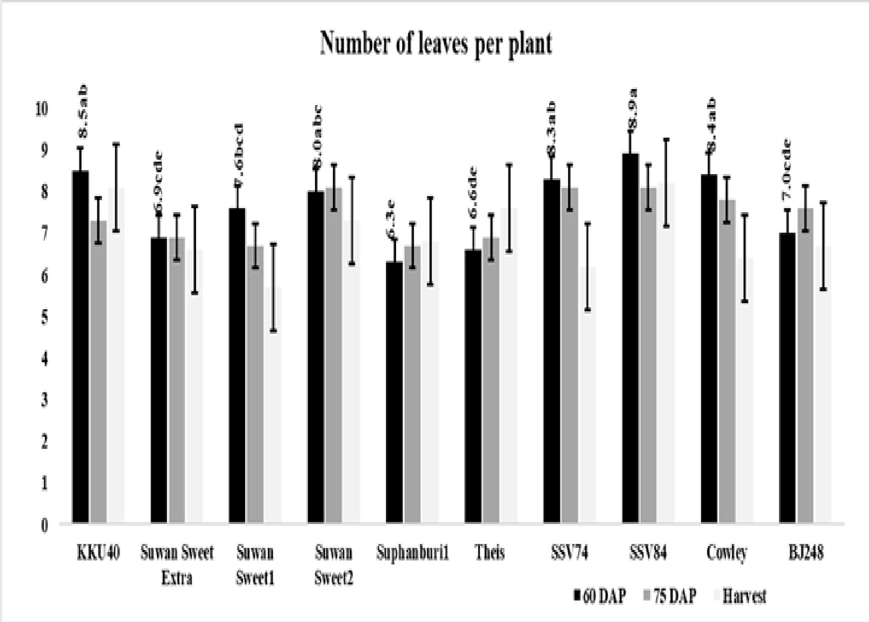

Fig. 4 Number of leaves per plant at 60 75 DAP and harvest day of ten sweet sorghum cultivars

Table 3. Juice yield, specific gravity of juice (SG), percent of ethanol and theoretical ethanol yield (TEY) of ten sweet sorghum cultivars grown during the late rainy season.

Cultivar	Juice yield (l ha^{-1})	SG	Percent ethanol(%)	Theoretical ethanol yield (l ha^{-1})
KKU40	12100b	1.053	8.16a	960.1ab
Suwan Sweet Extra	14230ab	1.014	8.18a	1155.7a
Suwan Sweet1	16017ab	1.035	6.35ab	483.9c
Suwan Sweet2	12550b	1.047	6.92ab	849.7ab
Suphanburi1	7022c	1.038	6.21ab	431.8c
Theis	842d	1.024	6.67ab	53.3d
SSV74	7867c	1.020	5.18b	399.4c
SSV84	17878a	1.024	5.31b	958.1ab
Cowley	14183ab	1.031	5.27b	644.2bc
BJ248	6472c	1.055	6.17b	408.0c
CV (%)	20.92	1.45	18.00	29.77
LSD	3916.7	-	1.99	323.96
F-test	**	ns	*	**
SE	1864.3	0.01	0.95	154.2

ns, * and **; non-significant, significant at p≤ 0.05 and 0.01 probability levels, respectively. Means in the same column with different letters are significantly different (p<0.05) determined by LSD.

growth stage. An interaction between cultivar and water regime was found in SCMR at vegetative, reproductive and physiological maturity stage (Bunphan et al., 2022).

Total soluble solids (TSS): this parameter which is a pivotal trait in sugar crops, was measured at harvest day, in the current study, the result revealed a significant difference among sweet sorghum cultivars with values ranging between 9.9-16.2 °brix, with cv. Suwan sweet extra recording the highest TSS (16.2 °brix) even though it did not significantly differ to KKU40, Suwan sweet2 and Theis (16.1, 14.2 and 14.1 °brix, respectively), whereas cv. SSV74 displayed the lowest TSS (9.9 °brix) (Fig. 6). The present results align with findings Bunphan et al. (2014) who found a significant difference in TSS among cultivars where cv. Theis and KKU40 had higher TTS similar to the current study, whereas cv. SSV84 also exhibited higher TSS (14.33 °brix) which was in contrast to the current study where it recorded lower TSS (11.8 °brix), In India, Chaithrashree et al. (2024) found that cv. SSV74 and SSV84 had higher total soluble solids (14.63 and 15.63 °brix, respectively) compared to a recent study, which reported increases of 32.3% and 24.5%, respectively, this is likely due to the varying management practiced during growth on the two studies. Nazli (2020) reported that TSS was significantly different among genotypes, year and genotypes × years, it ranged from 14.9-20.9 °brix and 13.3-22.9 °brix in 2017 and 2018, respectively, Rutto et al. (2013) reported that TSS was not significantly different among genotypes in the first year. However, in the second and third years of their study, TSS showed significant differences among genotypes, indicating that the environment played a role in the two years of study. However, other previous reports exhibited slightly lower TSS than in the recent study which could partly be attributed to the different ecological conditions which the crops were planted in. In humid subtropical regions, Han et al. (2012) reported that TSS ranged from 14.1-17.4 °brix in Louisiana, USA, 12.8-16.5 °brix in Florida, USA (Erickson et al., 2011), 13.0-16.8 °brix in Virginia (Kering et al., 2017). In semiarid tropics, Reddy et al. (2007) reported TSS ranged between 11.2 and 14.2 °brix in post-rainy season for ICSV 700 and ICSV 93046, respectively. In humid continental regions, Houx and Fritschi (2013) reported values of 12.9-15.9% in central Missouri, and Ali et al. (2008) reported brix values of 12.1-15.5% in eastern Nebraska, USA. El-Razek and Besheit (2009) reported average value of 17.8% for cv. Umbrella in a hot desert climate of northeastern Egypt. The differences in brix content among cultivars and various environments could be attributed to distinct genetic capacities inherent in each cultivar, coupled with specific soil and climate conditions (Dutra et al., 2018). However, Ekefre et al. (2017) did not find any significant difference in TSS among sweet sorghum cultivar, however, cv. Theis showed higher TSS (14.9 °brix) which was closer to the one recorded in current study (14.1 °brix), also Rono et al. (2016) found not-significant difference in TSS in sweet sorghum cultivars when studied at Mundika site, Busia county Turkey, grown in September-December, with ranges of 12.0-15.7 °brix. Whereas Fracasso et al. (2017) found significant differences in soluble sugar content ranging 6.2-15.5 °brix grown under soil loamy texture in Gariga di Podenzano, Northern Italy in Mediterranean environment, under rainfed and irrigation conditions.

Stripped stalk yield: is a crucial trait in sweet sorghum and sugarcane. The results of this study revealed a significant difference ($p \leq 0.01$) in stripped stalk yield among cultivars, stalk yield ranged 13.42-54.84 t ha^{-1}, cv. Cowley exhibited a higher stripped stalk yield at 54.84 t ha^{-1} compared to other cultivars. However, it did not significantly differ from cv. SSV84 and Suwan sweet extra, which recorded yields of 46.72 and 44.03 t ha^{-1}, respectively. In contrast, cv. Theis reported a lower stripped stalk yield (13.42 t ha^{-1}) in the current study (Fig. 7). During the rainy season in India, Umakanth et al. (2024) found that cv. SSV84 had a yield of 46.8 t ha^{-1}, which was very close to the yield reported in a recent study (46.72 t ha^{-1}), however, in the recent study, cv. SSV74 had yield that was 48.2% lower than in the previous study. Many previous reports found a significant difference in this parameter (Nazli and Polat, 2024, Nazli, 2020; Oktem et al., 2020; Naoura et al., 2019; Rono et al., 2016; Bunphan et al., 2014; Rutto et a., 2013). Stripped stalk yield had a significant difference among various cultivars in a present report and agreed with Nazli and Polat (2024) who recorded stripped stalk yield ranged from 21.04-58.81 t ha^{-1} in a summer season under Mediterranean climate conditions in Turkey, while yield ranging from 10.15-44.44 t ha^{-1} was recoded in Kenya when planting date at September-December (Rono et al., 2016). At Virginia State University, during three years of planting in the rainy season, yields ranged from 25.8-29.9 t ha^{-1} (no significant differences among genotypes) in the first year, 20.9-53.8 t ha^{-1} and 26.4-51.0 t ha^{-1} in the second and third year respectively, this indicates that, aside from genotype variations, the environment factor played a role in the differences in stalk yield (Rutto et al., 2013). Soil type showed to play a significant role in this trait as Nazli (2020) observed that planting sweet sorghum in clay loam soil recorded yield in the range of 24.0-74.0 t ha^{-1} whereas Bunphan (2014) recorded a slightly lower yield when planted in sandy soil in late rainy season.

Juice yield: this is the most important parameter of sweet sorghum as it determines whether the cultivar can be cultivated for commercial purposes. The results of the current study showed that juice yield was significantly different among various sweet sorghum cultivars ($p \leq 0.01$), cv. SSV84 exhibited higher juice yield (17878 l ha^{-1}) than other cultivars, however it did not differ with cv. Suwan sweet1, Suwan sweet extra and Cowley (16017, 14230 and 14183 t ha^{-1}, respectively), while cv. Theis recorded a significantly lower juice yield (842 l ha^{-1}) (Table 3). Several reports found a significant differences in this trait, with Rono et al. (2016) recording yield ranging from 2188-11146 l ha^{-1} in late rainy season and 761-9615 l ha^{-1} in early rainy season, Rutto et al. (2013), who studied juice yield over three rainy seasons, reported values ranging from 9700-12900 l ha^{-1} in the first year, 7600-23400 l ha^{-1} in the second year, and 9600-17000 l ha^{-1} in the third year. Compared to the recent study, the results are similar to their third-year findings, slightly higher than their first-year results, but slightly lower than their second-year outcomes. Yucel et al. (2022) recorded yield variation ranging between 22980-62740 l ha^{-1} grown under clay-loam soil and Nazli and Polat (2024) recorded a range which closely similar to a recent study at 5825-16105 kg ha^{-1} under Mediterranean climate conditions. On specific cultivar, cv Theis showed variation of yield when evaluated in different studies as in our study it recorded a low 842 l ha^{-1} whereas Ekefre et al. (2017) reported much higher yield of 9289 l ha^{-1} at the maturity stage, these

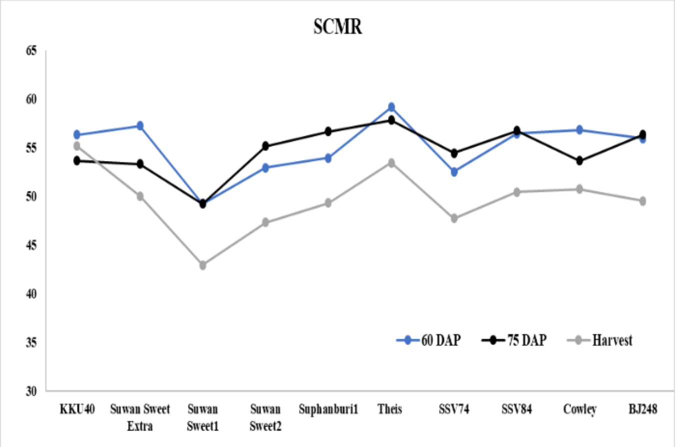

Fig. 5 SCMR at 60 75 DAP and harvest day of ten sweet sorghum cultivars.

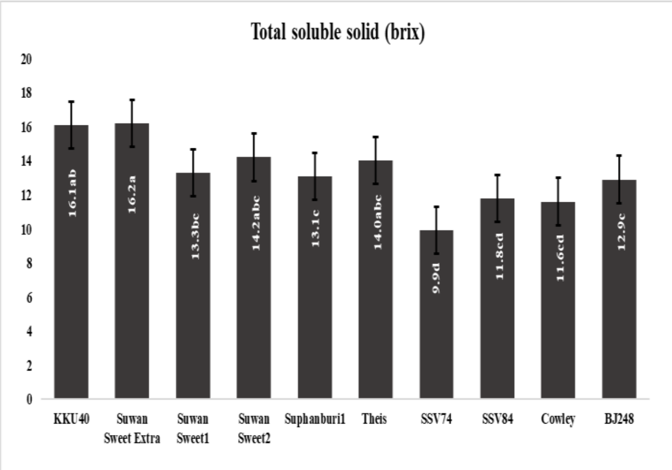

Fig. 6 Total soluble solids of ten sweet sorghum cultivars.

variations can be attributed to environmental effects thus suggesting the cultivar is suitable for specific environment only. *Specific gravity (SG):* it was determined by dividing juice yield by juice weight. Sweet sorghum juice is made up by sugars that influence specific gravity to exceed 1.0, this trait was employed in ethanol yield calculations using the formula proposed by Somani and Taylor (2003). The results revealed that SG did not differ significantly ($p > 0.05$) among sweet sorghum cultivars, with range of 1.020-1.055 (Table 3). This differs from the findings of Bunphan et al. (2022), who noted a significant difference in SG among the sweet sorghum varieties.

Percent ethanol: computed following Somani and Taylor (2003), this trait demonstrates a positive correlation with theoretical ethanol yield, as indicated by Bunphan et al. (2014). In the present study, the percentage of ethanol showed a significant difference among various cultivars ($p \leq 0.05$), ranging from 5.18 to 8.18%, several cultivars, including KKU40, Suwan sweet extra, Suwan sweet2, Theis, Suwan sweet1, and Suphanburi1, exhibited notably higher percentages of ethanol (Table 3), this finding aligns with the results of Bunphan et al. (2014), who also reported a significant difference on this trait. Furthermore, in both studies, cv. Theis consistently demonstrated a higher percent ethanol. Whereas Umakanth et al. (2024) reported that percent alcohol in various sweet sorghum cultivars ranged from 6.39-8.40% which was similar to the recent study, where both SSV74 and SSV84 were studied in both studies. The results revealed that in the previous study a higher percentage of alcohol was reported as compared to the current report, with increases of 33.6% for SSV74 and 25.63% for SSV84. This result was not surprising because the alcohol content is derived from the TSS value, and in the recent study, both cultivars had lower TSS values.

Theoretical ethanol yield (TEY): this parameter demonstrates a positive correlation with several traits i.e. plant height, stripped stalk weight, biomass yield, total soluble solid, harvest index and percent ethanol (Bunphan et al., 2014). This study indicated that TEY was significantly different ($p \leq 0.01$), among various cultivar of sweet sorghum. TEY ranged from 53.3-1155.7 l ha^{-1}, cv. Suwan sweet extra gave higher TEY (1155.7 l ha^{-1}) than other cultivars but was not significantly different from KKU40, SSV84 and Suwan sweet2 (960.1, 958.1 and 847.7 l ha^{-1}, respectively) (Table 3). The TEY from the current study was comparable to those reported in humid environments as Briand et al. (2018) reported values of 641-1496 l ha^{-1} in Maryland, USA, and Houx and Fritschi (2013) reported values of 407-1609 l ha^{-1} in central Missouri, USA, in case of the Virginia State University Rutto et al. (2013) reported values of 691-893 l ha^{-1} in first year, 532-1419 l ha^{-1} and 704-1544 l ha^{-1} in second and third year respectively, this indicates that different years or seasons affected TEY similarly to other traits. However, in the current study the TEY is considerably lower when compared with those reports probably because different sweet sorghum cultivars were used in their study. In a study conducted in semiarid that is similar to the current report, Oktem et al. (2020) found significant differences among genotypes, Bunphan et al. (2014) also found significant differences in TEY among 15 cultivars, recording ranges of 720.0-2708.3 l ha^{-1}, which were slightly higher than for current study. Moreover, cv. Theis demonstrated a higher TEY ranging from 3520-7619 l ha^{-1} when cultivated in sandy loam soil in Georgia, United States (Ekefre et al., 2017), this contrasts sharply with the TEY reported in this study, which recorded 53.3 l ha^{-1}. Oyier et al. (2017) found significant differences in absolute ethanol yield among genotypes, harvesting stage and interaction between genotype × harvesting stage was also noted. Genetic variations and the environment effects have been shown to impact crop yield, encompassing both juice and ethanol yield in sweet sorghum, thus it is advisable to employ suitable genotypes tailored to specific areas or select adaptive genotypes with broader environmental adaptability.

Grain yield: exhibited significant difference ($p \leq 0.01$) among sweet sorghum cultivars, ranging from 2.39-9.62 t ha^{-1}, cv. SSV84 demonstrated the highest grain yield (9.62 t ha^{-1}) but not significantly different to cv. Cowley (8.00 t ha-1), whereas cv. Theis recorded a lower grain yield (2.39 t ha^{-1}) (Fig. 8) contrary to Ekefre et al. (2017) reported that grain yield of cv. Theis was 1.3 t ha^{-1} which was lower than a recent study and the difference could be from environmental or management variation. Oyier et al. (2017) observed a significant difference in grain yield among various genotypes (3.05-4.27 t ha^{-1}), harvesting stage and their interaction. The head dry weight was significant difference among cultivars, it ranged from 0.9-1.8 t ha $^{-1}$ and cv. Thies showed lower grain yield (1.3 t ha^{-1}) than a recent study (2.39 t ha^{-1}). Rutto et al. (2013) also found a significant difference in this trait over a three-year study, with values ranging from 67 to 1351 kg ha^{-1}, which were lower than reported in a recent study. Interestingly, current results indicated that higher stalk yield was associated with higher grain yield in the same group (SSV84 and Cowley), suggesting that both cultivars could effectively be used as dual-purpose crops. However, it is noteworthy that these genotypes exhibited low total soluble solids.

Materials and methods

Plant materials

Ten pure lines sweet sorghum were used as treatment, five cultivars were imported from various countries i.e. Theis and Cowley were introduced from USA (Ali et al., 2008), SSV74 and SSV84 were kindly donated from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India and BJ248

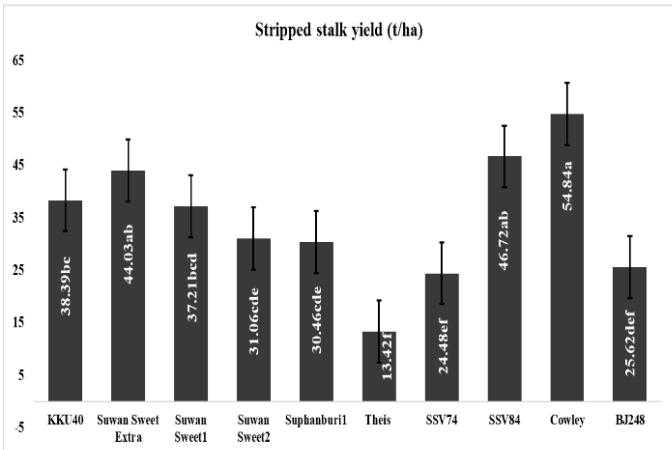

Fig. 7 Stripped stalk yield of ten sweet sorghum cultivars.

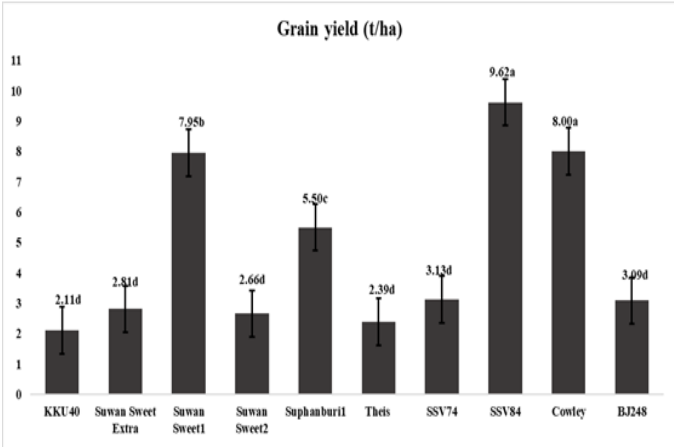

Fig. 8 Grain yield of ten sweet sorghum cultivars grown under late rainy season.

was introduced from China (Audilakshmi et al., 2010). The other five were developed by Thai breeders (i.e. Suwan sweet extra, Suwan sweet1 and 2, Suphanburi1 and KKU40,), cv. Suwan sweet extra, Suwan sweet1 and 2 were kindly donated from National Corn and Sorghum Research Center, Kasetsart University, Thailand, cv. Suphanburi1 was kindly donated from Suphanburi Field Crops Research Center, Suphanburi Thailand and cv. KKU40 which was released by Khon Kaen University in Thailand, was used as the control variety in this research.

Experimental design and agronomic practice

The field trial was carried out at Nasrinuan Research Center, Faculty of Technology, Mahasarakham University, Maha Sarakham province Thailand, in late rainy season (September to December 2022). The experiment was set up in randomized complete block design (RCBD) with three replications. The cultivars were planted in four-row plots with 5 m in length and spacing in 50 cm between rows and 20 cm between plants. The seeds were drilled manually into the soil and the seedlings were later thinned at 14 days after planting to obtain 1 plant per hill. The 15-15-15 (N-P-K) fertilizer at rate 156.25 kg ha^{-1} was applied at two splits during sowing and top dressing after planting 30 days or 4 weeks after manual weeding. Sweet sorghum was managed under rainfed condition and supplementary moisture was applied once a week by sprinkler system. Carbosulfan was used for protecting shoot fly damage with basal fertilizer when planting sweet sorghum.

Meteorological data

The average temperature, rainfall, cumulative rainfall and relative humidity (RH) were monitored on a monthly basis. The average temperature ranged from 18.0-32.7 °C from September to December with the lowest temperature recorded in December

(18 °C) and the highest in September (32.7 °C). The monthly rainfall varied between 0-397.7 mm, with September experiencing the highest rainfall at 397.7 mm, while no rainfall was observed in December. The cumulative rainfall over the crop cycle was recorded at 549.6 mm. The RH fluctuated between 66.8% and 84.4%, with the lowest RH occurring in December (66.8%) and the highest in September (84.4%).

Soil properties: Chemical composition and texture analyses were conducted on soil samples obtained from the 0-20 cm layer from experimental area. The soil exhibited a pH of 7.20, electrical conductivity (EC) of 18.0 μs/cm², organic matter (OM) content of 0.412%, total nitrogen (N) concentration of 0.0215%, and total phosphorus (P) and potassium (K) were 47.75 and 97.95 mg kg⁻¹, respectively. The distribution of sand, silt, and clay percentages in the soil was 85%, 7%, and 8%, respectively. The soil texture was identified as loamy sand.

Agronomic measurements

Number of days to 50% flowering was recorded when 50% of sweet sorghum in the plot had started flowering.

Plant height was recorded three times at 60, 75 and harvest day, five plants in each plot were recorded, plant height was measured from the ground level to the panicle tip of the stems.

Stalk diameter was measured using digital vernier caliper at the middle nodes of 5 plants in each plot, this trait was measured three times at 60, 75 and harvest day.

Number of leaves per plant was recorded three times at 60, 75 and harvest day, five plants in each plot were recorded, the fully expanded leaves were counted.

The soil plant analysis development (SPAD) chlorophyll meter reading (SCMR) was measured three times at 60, 75 and at harvest days. The SCMR was measured in five plants in each plot at 3rd leaf from the top on three positions of leaf blade using Minolta SPAD-502 meter.

Sweet sorghum in each plot were harvested manually at hard dough stage or 30 days after days to 50% flowering by cutting the stems at the base of the plants with a scissor.

Total soluble solid (TSS) (°brix) was measured using hand-held refractometer at harvest day or 30 days after 50% flowering. Total soluble solid was recorded from three parts of five stems (base, middle and tip) and the data were averaged into single value for each plot.

Stripped stalk yield or cane yield was measured from 4.6 m^2 in each plot by removing panicle and leaves and the data were converted to yield per hectare.

Juice yield, 5 plants were used after removing the panicle and leaves, were then squeezed through small sugarcane extractor and juice collected was then measured to determine the yield.

Specific gravity (SG) of juice was calculated with simply formula $SG=\frac{M}{V}$ when M is mass of juice (ml) and V is volume of juice (g). This trait is used for ethanol yield calculation.

Percent ethanol and theoretical ethanol yield were calculated following Somani and Taylor (2003).

Grain yield was recorded at 4.6 m^2 in each plot (consisting of two rows per plot excluding guard rows) and the values were subsequently converted to a per-hectare basis. At sweet sorghum stalk maturity, the grains were sun-dried over a period of 3-7 days and manually threshed by hand.

Statistical analysis

All data recorded was analyzed using Statistix 10. An analysis of variance (ANOVA) was exercised to verify the overall significance of data. The least significance difference (LSD) test was employed to compare the means at 5% probability level (Steel and Torrie, 1960).

Conclusion

This research successfully addressed the study objectives by investigating the effect of genetic variation and environmental factors on agronomic traits, yield parameters and the potential for ethanol production in sweet sorghum. The study focused on observations made during one season, specifically the late rainy season. From the result, it can conclude that outstanding cultivars i.e. cv. Suwan sweet extra, when considered by stalk yield, ethanol yield and total soluble solid, although cv. SSV84 and Cowley had low total soluble solid, but both cultivars exhibited higher stalk yield, ethanol yield and grain yield, therefore the suggestion for utilize both cultivars could be effectively used as dual-purpose crops. The study suggests that exotic cultivars from the USA, such as cv. Cowley, and India, represented by cv. SSV84, exhibit promising adaptability to loamy sand soil with low fertility levels. Nevertheless, it is crucial to conduct yield trials across different seasons and diverse environments, incorporating a broader range of both local and exotic cultivars. This ongoing research is deemed necessary to further enhance our understanding and provide valuable insights for future cultivation practices.

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