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Yield Potential, Heterosis and Ethanol Production in F_1 Hybrids of Sweet Sorghum (*Sorghum bicolor* L. Moench)

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Abstract

Sweet sorghum is a potential raw material for food, feed, and fuel. The objective of this research was to study on agronomic yields and ethanol production in sweet sorghum F_1 hybrids in Thailand. Twenty sweet sorghum F_1 hybrids of crossed between 10 A-lines with 2 R-lines; KKU40 and Urja were tested in dry season during December 2009 to March 2010 at the National Corn and Sorghum Research Center with male parent lines and 8 checked varieties; Suphanburi 1, Cowley, Keller, Rio, Wray, Suwan Sweet #1, Suwan Sweet #2, and Suwan Sweet #3. RCBD with 3 replications was used. The result revealed that F_1 hybrids had 39.75-56.04 tons ha^{-1} of stripped stalk yield, 32.27-52.93 percent cane juice extracted, 13.07-16.00 percent brix, and 0.88-2.21 kl ha^{-1} of ethanol yield. L103/KKU 40 gave the highest stripped stalk yield with high percentage of cane juice extracted and percent brix of 51.71 and 15.07%, respectively. L103/Urja gave the highest ethanol yield, percent brix, and grain yield. L104/Urja gave highest percent cane juice extracted but low percent brix, 13.80%. All F_1 hybrids were early maturity and tall stature. The earliest F_1 hybrids, 55 days to flowering were L101/Urja, L102/KKU40, L106/Urja and L107/KKU 40 and the tallest, 308 cm height were L103/KKU40 and L104/KKU40. Male parent lines KKU 40 and Urja had 48.33 and 48.53 tons ha^{-1} of stripped stalk yield, 39.24 and 37.83 percent cane juice extracted, 13.70 and 14.87 percent brix, and 1.28 and 1.37 kl ha^{-1} of ethanol yield. The means of checked varieties were 50.18 tons ha^{-1} of stripped stalk yield, 43.44 percent cane juice extracted, 14.93 percent brix, and 1.64 kl ha^{-1} ethanol yield. These F_1 hybrids showed % heterosis over better male parent for days to flowering, plant height, percent brix, stripped stalk yield, grain yield, and percent cane juice extracted up to -7.83, 8.06, 7.60, 15.47, 66.33 and 34.89%, respectively. The high potential F_1 hybrids were L103/KKU40, L103/Urja, L104/KKU40, L102/Urja, and L106/Urja.

Keywords: Sweet sorghum, F_1 hybrid, agronomic yields, ethanol production

1. Introduction

Sweet sorghum (*Sorghum bicolor* L. Moench) or sweet stalk sorghum is a high potential field crop for food, feed, and fuel. Its grain is used for food and feed, juice for alcohol production and stalks are used as silage or fodder. In recent years, the energy crisis and environmental pollution have become more serious. So, many countries look for green energy from biomass and sweet sorghum

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is such an ideal alternative. Increasing productivity of sorghum can be achieved by adopting improve agronomic practices and using F_1hybrid cultivars. Growing sweet sorghum hybrid with high cane juice, sweetness and the total fermentable sugars is consider to be a high efficiency in producing ethanol. In USA, the sorghum production has tripled since the adoption of hybrid sorghum cultivars and exploitation of hybrid vigor in conjunction with intensive management practices [1,2]. The heterosis or hybrid vigor is the expressions of the F1 hybrid over its parents. Heterosis in sorghum was first observed in 1927 [3], but commercial exploitation was not possible until the discovery of cytoplasmic genetic male sterility system by Stephens and Holland in 1954 [4]. Most of the sweet sorghum varieties mature between 115 and 125 days during rainy season. Stalks can be harvested along with grain. The green cane yield varies from 30 to 50 tons ha^{-1}, and grain yield from 0.8 to 2.0 tons ha^{-1} with a brix value of 16 to 20%. Sweet sorghum varieties and hybrids bred at NRCS, India have potential to produce biomass up to 48 tons ha^{-1} and 1.5 to 2.9 tons ha^{-1} grain with brix value of 14 to 18% [5]. The juicy stalks of sweet sorghum can be used for preparation of syrup, jaggery and fuel grade ethanol. Sweet sorghum has ability to yield 40-45 tons ha^{-1} millable cane and 1-1.5 tons ha^{-1} grain, and an average brix of 18.4%. The juice has a minimum of 12% sucrose and at least 15% total fermentable sugar [6]. Ethyl alcohol, the finished product of fermentation has high commercial value. It is a “clean burning fuel” with high octane rating and the existing automobile engines can be operated with petrol blended with 20% ethanol (80% petrol) without needed for engine modifications. The alcohol yield can be estimated using the formula proposed by Somani and Taylor [7].

% of alcohol = (brix-3) x specific gravity x 0.59.

At present, very few hybrids of sweet sorghum are released. In 2005, ICRISAT (India) recommended 8 pure lines sweet sorghum to public namely NTJ2, SPV422 (ICSV574), SPV1411, ICSR93034, ICSV93046, ICSV700, S35, and E36-1. In 2008, it was reported that two pure lines, SSV84 and CSV19 and one hybrid, CSH 22 (NSSH104) were used in the research on a potential energy crop for bio-fuel production in India [8]. Hence, to choose the high potential sweet sorghum for growing in Thailand, the objectives of this research were to evaluate the potential of sweet sorghum F_1 hybrids which developed by the Sorghum Breeding Program of Kasetsart university in productivity and ethanol yield.

2. Materials and Methods

2.1 Genetics materials

2.1.1 Twenty F_1 hybrids sweet sorghum derived from 10 A-lines; L101/KKU40, L101/Urja, L102/KKU40, L102/Urja, L103/KKU40, L103/Urja, L104/KKU40, L104/Urja, L105/KKU40, L105/Urja, L106/KKU40, L106/Urja, L107/KKU40, L107/Urja, L108/ KKU40, L108/Urja, L109/KKU40, L109/Urja, L110/KKU40, and L110/Urja,

2.1.2 Two male parental lines; KKU 40 and Urja

2.1.3 Eight checked varieties; Suphanburi 1, Cowley, Keller, Rio, Wray, Suwan Sweet #1, Suwan Sweet #2, and Suwan Sweet #3.

2.2 Methods

Twenty F_1 hybrids were tested in dry season during December 2009 to March 2010 along with two male parents and 8 checked varieties. The trial laid out in Randomized Complete Block Design (RCBD) with 3 replications, at the National Corn and Sorghum Research Center (NCSRC), Pakchong district, Nakhon Ratchasima province. The experimental plot size was 3 x 4 m, 4 rows per plot. Plant spacing was 0.75 x 0.08 meter, 1 plant per hill. The 16-20-0 grade fertilizer was used as basal fertilizer at the rate of 187.50 kg ha^{-1} and Urea (46-0-0) used for top-dressing at the

same rate when sorghum plant was 28 days after germination. Carbosulfan was sprayed to protect seedling from shootfly damage at 15 days after germination. Sprinkler irrigation system was used from planting up to 1 month after that furrow irrigation was practiced up to physiological maturity. Data of 6 traits; days to flowering, plant height, percent brix, stripped stalk yield, grain yield, and percent cane juice extracted, were collected according to the instruction for data collection on various traits of sweet sorghum by IBPGR/ICRISAT [9].

2.3 Statistical analysis

2.3.1 Analysis of variance for data from RCBD and heterosis (better parent, and standard hetrosis) were done using R program Version 2.11.1 (The R Foundation for Statistic Computing ISBN 3-900051-07-0) [10].

2.3.2 The alcohol yield was estimated from stripped stalk yield, percent cane juice extracted, specific gravity and percent brix by this formula:

% of alcohol = (brix-3) x specific gravity x 0.59

3. Results and Discussion

3.1 Yield and agronomic characters of sweet sorghum

Yields of twenty sweet sorghum F_1 hybrids are showed in Table 1. The analysis of mean data showed significant difference among entries. The F_1 hybrids had 55 - 62 days to flowering, 253-308 cm of plant height, 13.07-16.00 percent brix, 39.75-56.04 tons ha^{-1} of stripped stalk yield, 2.88-4.89 tons ha^{-1} of grain yield at 15 percent grain moisture, and 32.27-52.93 percent cane juice extracted. The means of F_1 hybrids were 57.43 days to flowering, 284 cm of plant height, 14.13 percent brix, 49.45 tons ha^{-1} of stripped stalk yield, 3.72 tons ha^{-1} of grain yield, and 43.79 percent cane juice extracted. Male parental lines; KKU40 and Urja had 60 and 68 days to flowering, 259 and 285 cm of plant height, 13.70 and 14.87 percent brix, 48.33 and 48.53 tons ha^{-1} of stripped stalk yield, 2.94 to 2.90 tons ha^{-1} of grain yield, and 39.24 and 37.83 percent cane juice extracted. The checked varieties had 61-76 days to flowering, 216-304 cm of plant height, 13.27-17.53 percent brix, 36.81-54.06 tons ha^{-1} of stripped stalk yield, 2.19-3.90 tons ha^{-1} of grain yield, and 31.62-50.64 percent cane juice extracted. The means of checked varieties were 67.29 days to flowering, 284 cm of plant height, 14.93 percent brix, 50.18 tons ha^{-1} of stripped stalk yield, 3.28 tons ha^{-1} of grain yield, and 43.44 percent cane juice extracted. It was found that L101/Urja, L102/KKU40, L106/Urja and L107/KKU40 were superior in days to flowering, L103/KKU40 and L104/KKU40 in plant height, Cowley in percent brix, L103/KKU40 in stripped stalk yield, L103/Urja in grain yield and L104/Urja in percent cane juice extracted. The high potential F_1 hybrids were L103/KKU40, L103/Urja, L104/KKU40, L102/Urja, and L110/KKU40. In this study, 4 recommended pure lines of sweet sorghum; Suphanburi 1, Suwan Sweet#1, Suwan Sweet #2, and Suwan Sweet#3 which developed by sorghum breeding program in Thailand for both grain and stalk yield had higher grain or stalk yield. Suphanburi 1 had moderately high grain yield with high percent brix but lower stripped stalk yield. KKU40 was a pure line sweet sorghum with moderately high stripped stalk yield and percent brix, but it had small grain and lower grain yield. Suwan Sweet#1, Suwan Sweet#2, and Suwan Sweet#3 produced moderately high stripped stalk yield, percent cane juice extracted, and grain yield but they had relatively low percent brix. Sweet sorghum F_1 hybrids had high potential to improve yield and some agronomic characters for better productivity such as L103/KKU40, L103/Urja, L104/KKU40, L102/Urja, and L106/ KKU40. However, other agronomic characters that affect yield component such as yield of ratoon crops for second and third cutting should be studied before recommendation for commercial production.

Table 1 Mean of days to flowering, plant height, percent brix, stripped stalk yield, grain yield and percent cane juice extracted of sweet sorghum F_1 hybrids, male parent lines, and standard checked varieties tested in dry season 2010.

Hybrid No.	Pedigree	Days to flowering	Plant height (cm)	Percent Brix	Stripped stalk yield (t ha^{-1})	Grain yield (t ha^{-1})	% cane juice extracted
5	L103/KKU40	58	308	15.07	56.04	3.81	51.71
11	L106/KKU40	58	302	13.33	54.41	3.13	51.01
6	L103/Urja	59	274	16.00	54.24	4.89	49.83
4	L102/Urja	56	306	14.33	52.62	3.93	48.48
7	L104/KKU40	57	308	14.40	52.39	4.63	46.01
14	L107/Urja	59	287	13.80	52.19	2.97	39.71
10	L105/Urja	56	274	13.70	52.18	3.20	49.43
2	L101/Urja	55	303	13.67	51.98	3.24	45.08
12	L106/Urja	55	271	14.67	51.38	3.33	49.65
8	L104/Urja	56	300	13.80	51.01	3.62	52.93
19	L110/KKU40	56	253	14.47	50.91	4.16	41.58
13	L107/KKU40	55	267	13.07	49.10	4.39	40.54
16	L108/Urja	61	281	14.20	48.82	4.11	42.47
9	L105/KKU40	59	285	13.07	48.08	4.07	39.45
3	L102/KKU40	55	296	14.17	47.31	2.88	38.51
15	L108/KKU40	62	291	13.70	46.75	3.13	42.48
20	L110/Urja	61	281	15.27	46.46	3.95	38.00
1	L101/KKU40	56	283	13.60	45.85	3.63	39.64
17	L109/KKU40	60	271	14.33	43.58	3.78	37.08
18	L109/Urja	56	256	13.87	39.75	3.62	32.27
21	KKU 40	60	259	13.70	48.33	2.94	39.24
22	Urja	68	285	14.87	48.53	2.90	37.83
23	Suphanburi 1	61	216	15.67	36.81	3.85	31.62
24	Cowley	76	269	17.53	49.99	2.19	41.67
25	Keller	68	295	14.20	51.28	3.29	43.24
26	Rio	66	303	13.87	51.15	3.90	41.48
27	Wray	67	296	15.80	52.53	2.96	50.64
28	Suwan sweet #1	67	304	13.27	52.99	3.85	48.03
29	Suwan sweet #2	67	294	14.27	54.06	3.06	48.60
30	Suwan sweet #3	67	295	14.87	52.62	3.15	42.26
	F-test	**	**	**	**	**	**
	LSD.01	2.298	12.850	1.030	1.970	0.279	2.747
	C.V.%	1.75	2.09	3.30	1.82	3.67	2.92

3.2 Heterosis in sweet sorghum F_1 hybrids

Heterosis and range of expression of 6 characters under investigation among parent and F_1 hybrids are shown in Table 2. Days to flowering, better parent heterosis ranged from -7.83 to 3.35%. The F_1 hybrids, L101/Urja, L106/KKU40 and L107/KKU40 showed the highest negative heterosis of -7.83%. Plant height, better parent heterosis ranged from -11.33 to 8.06%. The F_1 hybrids, L103/KKU40 and L104/KKU40 showed the highest positive heterosis of 8.06 and 7.83%, respectively. Percent brix, better parent heterosis ranged from -12.13 to 7.60%. The F_1 hybrids, L103/Urja showed the highest positive heterosis of 7.60%. Stripped stalk yield, better parent heterosis ranged from -18.09 to 15.47%. The F_1 hybrids had wide range of heterosis for stripped stalk yield and L103/KKU40, L106/KKU40 and L103/Urja showed the highest positive heterosis of 15.47, 12.12, and 11.77%, respectively. Grain yield, better parent heterosis ranged from -2.04 to 66.33%. The F_1 hybrids exhibited higher grain yield over better parent were L103/Urja and L104/KKU40 with the heterosis of 66.33 and 57.48 %, respectively. Percent cane juice extracted, better parent heterosis ranged from -17.76 to 34.89%. The F_1 hybrids had wide range of heterosis. L104/ Urja and L103/KKU40 had the highest positive heterosis of 34.89 and 31.78%, respectively. The advantage of these F_1 hybrids found in early maturity, high stripped stalk yield, percent cane juice extracted and grain yield which suitable for dual purpose. The heterosis of these F_1 hybrids was very high in grain yield as in grain sorghum but relatively low in percent brix and stripped stalk yield which were important characters of sweet sorghum. Hence, the female parent lines should be improved not only lines *per se* performance but general combining ability also. At present, the meager genetic diversity of sweet sorghum in Thailand is the most important criteria for crop improvement. But the efforts are underway at the NCSRC to develop sweet sorghum hybrids with high percent brix, high juice content and biomass for food, feed, and fuel.

3.3 Ethanol production

Estimation of ethanol yields are shown in Table 3. These F_1 hybrids produced 0.88-2.21 kl $ha^{-1}$of ethanol. The L103/Urja and L103/ KKU40 gave the highest ethanol volume per unit area of 2.21 and 2.20 kl ha^{-1}, respectively. KKU40 and Urja, the male parent produced 1.28 and 1.33 kl $ha^{-1}$of ethanol, respectively. The checked varieties produced 0.93-2.14 kl $ha^{-1}$of ethanol. The mean of ethanol yield of 20 F_1 hybrids, 2 male parent lines, and 8 standard checked varieties were 1.54, 1.33 and 1.64 kl ha^{-1}, respectively. Two sweet sorghum F_1 hybrids gave the highest volume of ethanol. The improvement of new parent lines (both male and female parent lines) is necessary for higher yield component of ethanol production including percent brix, stripped stalk yield, percent cane juice extracted and cane juice volume.

4. Conclusions

Twenty sweet sorghum F_1 hybrids had desirable characters including early to medium maturity, taller plant with higher grain yield than their parent and checked varieties. Total soluble solids (percent brix) were medium, ranged from 13.60-16.00% with high percentage of cane juice extracted. They produced high stripped stalk yield and grain yield as well. They exhibited heterosis (%) over the better parent in all traits. These F_1 hybrids showed better percentage of heterosis over male parent for days to flowering, plant height, percent brix, stripped stalk yield, grain yield, and percent cane juice extracted up to -7.83, 8.06, 7.60, 15.47, 66.33 and 34.89%, respectively. Five high potential F_1 hybrids were L103/ KKU40, L103/Urja, L104/KKU40, L102/Urja, and L106/ Urja. The estimation of ethanol yield of 20 F_1 hybrids showed that the highest volume of ethanol was from L103/Urja and L103/KKU40 with the amount of 2.21 and 2.20 kl ha^{-1}, respectively.

Table 2 Heterosis (%) of 20 sweet sorghum F_1 hybrids

Hybrid No.	Pedigree	Days to flowering	Plant height	Percent brix	Stripped stalk yield	Grain yield	Percent cane juice extracted
1	L101/KKU 40	-6.70	-0.93	-8.54	-5.52	23.47	1.02
2	L101/Urja	-7.83	6.08	-8.09	7.11	10.20	14.88
3	L102/KKU 40	-7.27	3.74	-4.73	-2.51	-2.04	-1.86
4	L102/Urja	-6.15	7.24	-3.61	8.43	33.67	23.55
5	L103/KKU 40	-2.24	8.06	1.32	15.47	29.59	31.78
6	L103/Urja	-1.68	-3.86	7.60	11.77	66.33	20.99
7	L104/KKU 40	-5.03	7.83	-3.16	7.95	57.48	17.25
8	L104/Urja	-5.59	5.03	-7.20	5.11	23.13	34.89
9	L105/KKU 40	-1.12	-0.23	-12.13	-0.93	38.44	0.54
10	L105/Urja	-6.15	-3.97	-7.87	7.52	8.84	25.97
11	L106/KKU 40	-2.80	5.73	-10.34	12.12	6.46	29.99
12	L106/Urja	-7.83	-4.91	-1.37	5.87	13.27	26.53
13	L107/KKU 40	-7.83	-6.42	-12.13	1.17	49.32	3.31
14	L107/Urja	-1.68	0.59	-7.20	7.54	1.02	1.20
15	L108/KKU 40	3.35	2.10	-7.87	-3.67	6.46	8.26
16	L108/Urja	2.23	-1.63	-4.51	0.60	39.80	8.23
17	L109/KKU 40	1.11	-5.02	-3.63	-10.20	28.57	-5.50
18	L109/Urja	-6.71	-10.39	-6.72	-18.09	23.13	-17.76
19	L110/KKU 40	-6.70	-11.33	-2.69	4.90	41.50	5.96
20	L110/Urja	1.68	-1.52	2.69	-4.27	34.35	-3.16

Table 3 Stripped stalk yield, percent cane juice extracted, cane juice volume, specific gravity, percent brix, and alcohol volume of sweet sorghum F_1 hybrids, male parents and the best checked varieties tested in dry season 2010.

Entry No.	Pedigree	Stripped stalk yield (t ha^{-1})	Percent cane juice extracted	Cane juice volume (kl ha^{-1})	Specific gravity	Percent brix	Alcohol volume (kl ha^{-1})
6	L103/Urja	54.24	49.83	27.03	1.064	16.00	2.21
5	L103/KKU40	56.04	51.71	28.98	1.065	15.07	2.20
12	L106/Urja	51.38	49.65	25.51	1.065	14.67	1.87
8	L104/Urja	51.01	52.93	27.00	1.065	13.80	1.83
4	L102/Urja	52.62	48.48	25.51	1.065	14.33	1.82
11	L106/ KKU40	54.41	51.01	27.75	1.066	13.33	1.80
7	L104/ KKU40	52.39	46.01	24.10	1.066	14.40	1.73
10	L105/Urja	52.18	49.43	25.79	1.065	13.70	1.73
2	L101/Urja	51.98	45.08	23.43	1.064	13.67	1.57
19	L110/ KKU40	50.91	41.58	21.17	1.066	14.47	1.53
16	L108/Urja	48.82	42.47	20.73	1.064	14.20	1.46
14	L107/Urja	52.19	39.71	20.72	1.065	13.80	1.41
20	L110/Urja	46.46	38.00	17.65	1.065	15.27	1.36
15	L108/ KKU40	46.75	42.48	19.86	1.065	13.70	1.34
3	L102/ KKU40	47.31	38.51	18.22	1.066	14.17	1.28
13	L107/ KKU40	49.10	40.54	19.91	1.066	13.07	1.26
1	L101/ KKU40	45.85	39.64	18.17	1.065	13.60	1.21
9	L105/ KKU40	48.08	39.45	18.97	1.066	13.07	1.20
17	L109/ KKU40	43.58	37.08	16.16	1.066	14.33	1.15
18	L109/Urja	39.75	32.27	12.83	1.065	13.87	0.88
21	KKU40 (male parent 1)	48.33	39.24	18.96	1.066	13.70	1.28
22	Urja (male parent 2)	48.53	37.83	18.36	1.065	14.87	1.37
23	Wray (best check)	52.53	50.64	26.60	1.065	15.80	2.14

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