General and Specific Combining Ability of F_1 Hybrid Sweet Sorghum in Thailand

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Introduction

Sweet sorghum (*Sorghum bicolor* L. Moench) is a sugar crop similar to sugarcane, juice in stalk has rich-sugar and it can be fermented by yeast to produce bio-ethanol. As a biofuel crop, sweet sorghum has many favorable characteristics such as wide adaptability, rapid growth, drought tolerance, and high biomass production. Although sweet sorghum is highly productive, replacing the current inbred line sweet sorghum cultivars with hybrids could increase stalk and sugar yields. The development of hybrid sorghum relies on a cytoplasmic-genetic male sterility system, which requires male-sterile (A), sterility-maintainer (B), and fertility-restorer (R)–lines. An A-line (female) and R-line (male) are crossed to produce a male-fertile F_1 hybrid. The B-line (male) is crossed with its sister A-line to regenerate the male-sterile seed parent. This system has been used for decades in grain and forage sorghum, but only recently has it been applied to sweet sorghum. In sweet sorghum, non-restorer B-lines can also be used as pollen parents if male-sterile hybrids that do not produce grain are desired (Pfeiffer et al., 2010). Recent studies have shown the value of hybrid sweet sorghum for biofuel production, and also combining ability of F_1 hybrid sweet sorghum; however, there is little knowledge of combining ability of F_1 hybrid sweet sorghum in Thailand. Therefore the objectives of this study were to evaluate general and specific combining abilities of 15 F_1 hybrids sweet sorghum to determine which crosses are most effective for bio-ethanol production in Thailand.

Materials and Methods

• Plant materials and experimental size

The experiment was conducted at the Field Crops Research Station, Khon Kean University (Aug 22 2013) and National Corn and Sorghum Research Center (NCSRC) (Sept 9 2013). Fifteen F_1 hybrids sweet sorghum were evaluated. A randomized complete block design with 3 replications with seed spacing 75 x 10 cm and each plot was four rows of 4 m length. A basal fertilizer (grade 15-15-15 NPK at rate 156 kg ha^{-1}) was applied at planting and again one month after planting. Weeds were controlled by hand weeding before applying fertilizer, and irrigation was applied once per a week.

• Data collection

- Days to flowering
- Brix
- Plant height
- Stalk diameter
- Biomass yield
- Stripped stalk yield
- Theoretical juice yield
- Theoretical sugar yield
- Grain yield

• Data analysis

Analysis of variance for combining ability was carried out using only the data from hybrid entries. Location, female parent effect (GCA_{female}), male parent effect (GCA_{male}), and all possible interactions were included as fixed effects with replications as a random effect, nested within location. Significance of individual GCA and SCA effects was determined using the analysis of means (PDIFF=ANOM) option in the LSMEANS statement.

Results

Mid-parent heterosis is shown in Table 1. Significant Brix and theoretical sugar yield mid-parent heterosis were all negative, while the other 5 characteristics showed both significant positive and negative mid-parent heterosis. GCA for 9 characteristics of 8 parents is shown in Table 2. GCA for Brix was significant for all of female parents except KKA-14. GCA for plant height was significantly positive for female parent KKA-14 and male parent KKU40. GCA for biomass yield, stripped stalk yield, theoretical juice yield and grain yield were highly significant for the male parents. Only KKA-53 was positively significant for theoretical sugar yield and KKA-11 was positively significant in stripped stalk yield, theoretical juice yield and grain yield. SCA of 15 hybrids sweet sorghum were also measured and shown in Table 3. Results in red indicate significantly positive SCA for numerous traits.

Table 1 Percent mid-parent heterosis for seven biofuel traits of sweet sorghum hybrids grown at two locations in Thailand in 2013 and only significant values are shown

Hybrid	Plant height	Brix	Biomass yield	Stripped stalk yield	Theor. juice yield	Theor. sugar yield	Grain yield
KKA-11 × BJ248	20.0	-29.9	35.6	39.2	41.9	-	66.4
KKA-11 × KKU40	-	-	-	-	-	-41.7	-
KKA-11 × Theis	-	-27.1	-	-	-	-56.1	50.8
KKA-139 × KKU40	-	-26.1	-	-	-	-50.5	-
KKA-139 × Theis	-	-	-34.8	-35.5	-37.0	-37.7	-
KKA-14 × BJ248	-	-30.6	-	-	-23.9	-54.7	-
KKA-48 × BJ248	-	-	32.2	-	-	-	44.8
KKA-48 × KKU40	-	-	-	-32.5	-38.2	-41.4	-
KKA-53 × BJ248	18.0	-	-	-	-	-	39.0
KKA-53 × KKU40	-	-34.8	24.9	-	-	-45.1	28.1
KKA-53 × Theis	-	-	-	-	-	-	-44.6

Table 2 General combining ability (GCA) effects (deviations from the mean) for key biofuel traits of five female parents and three male parents of sweet sorghum in hybrid combinations, across two locations in Thailand

	Days to flowering (d)	Brix	Plant height (cm)	Stalk diameter (mm)	Biomass yield (t ha^{-1})	Stripped stalk yield (t ha^{-1})	Theor. juice yield (l ha^{-1})	Theor. sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
Females:									
KKA-11	-0.20^{ns}	-0.91**	-6.11^{ns}	0.53^{ns}	-0.01^{ns}	1.89*	1622*	-134 ^{ns}	0.57***
KKA-139	-0.31^{ns}	0.82**	-0.02^{ns}	0.24^{ns}	3.39^{ns}	-0.65^{ns}	-683 ^{ns}	270*	0.76***
KKA-14	-0.42^{ns}	0.32^{ns}	10.13*	-0.16^{ns}	-3.35^{ns}	-2.89**	-2513**	-21 ^{ns}	-0.22^{ns}
KKA-48	-0.37^{ns}	-1.06***	-3.66^{ns}	-0.04^{ns}	4.38*	1.38^{ns}	1379 ^{ns}	-554***	0.22 ^{ns}
KKA-53	1.30*	0.83**	-0.34^{ns}	-0.57*	-4.40*	0.27^{ns}	195 ^{ns}	439***	-1.33***
Males:									
BJ248	0.76ns	-0.34ns	-0.46^{ns}	0.62**	4.97***	2.86***	2507***	146*	0.73***
KKU40	-0.31ns	-0.01ns	9.71***	-0.02^{ns}	5.54***	2.49***	2106***	47 ^{ns}	0.52***
Theis	-0.44ns	0.35ns	-9.26**	-0.59**	-10.50***	-5.35***	-4613***	-248**	-1.25***

*, **, and *** indicate that the GCA is significantly different from the mean at $\alpha \leq 0.05$, 0.01, and 0.001, respectively; ns = not significant

Table 3 Specific combining ability (SCA) effects (deviations from the mean) for key biofuel traits of five female parents and three male parents of sweet sorghum in hybrid combinations, across two locations in Thailand

Hybrids	Days to flowering (d)	Brix	Plant height (cm)	Stalk diameter (mm)	Biomass yield (t ha^{-1})	Stripped stalk yield (t ha^{-1})	Theor. juice yield (l ha^{-1})	Theor. sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
KKA-11 × BJ248	3.86**	-1.80**	27.25***	1.88***	13.95***	12.34***	10439 ***	434 *	2.09 ***
KKA-11 × KKU40	-2.48*	1.02^{ns}	-4.60^{ns}	0.48^{ns}	-1.56^{ns}	3.42*	2813 *	683 **	-0.10 ns
KKA-11 × Theis	-1.98^{ns}	-1.95***	-40.98***	-0.77^{ns}	-12.43***	-10.09***	-8386 ***	-1091 ***	-0.27 ns
KKA-139 × BJ248	-0.64^{ns}	2.00***	-11.49^{ns}	1.23*	6.72^{ns}	0.95^{ns}	772 ns	831 ***	1.24 ***
KKA-139 × KKU40	1.52^{ns}	0.01^{ns}	18.42*	-0.75^{ns}	6.75^{ns}	-0.34^{ns}	-650 ns	-31 ns	1.30 ***
KKA-139 × Theis	-1.81^{ns}	0.47^{ns}	-6.99^{ns}	0.23^{ns}	-3.31^{ns}	-2.56^{ns}	-2170 ns	83 ns	-0.27 ns
KKA-14 × BJ248	0.19^{ns}	-1.78**	-5.61^{ns}	-0.09^{ns}	-2.48^{ns}	-2.50^{ns}	-1853 ns	-482 *	0.57 *
KKA-14 × KKU40	1.86^{ns}	0.78^{ns}	32.89***	0.56^{ns}	9.22*	3.89*	3197 *	774 **	-0.08 ns
KKA-14 × Theis	-3.31**	1.94***	3.12^{ns}	-0.95^{ns}	-16.79***	-10.06***	-8883 ***	-200 ns	-1.15 ***
KKA-48 × BJ248	-0.48^{ns}	-2.29***	3.84^{ns}	1.34*	19.58***	7.62***	6875 ***	-239 ns	0.69 **
KKA-48 × KKU40	-3.64 **	-1.73**	-0.10^{ns}	0.46^{ns}	12.64***	6.07***	5681 ***	-923 ***	1.73 ***
KKA-48 × Theis	3.02*	0.82^{ns}	-14.73*	-1.91***	-19.09***	-9.54***	-8419 ***	-436 *	-1.76 ***
KKA-53 × BJ248	0.86^{ns}	2.19***	-16.30*	-1.27*	-12.94***	-4.08*	-3696 **	399 ns	-0.96 ***
KKA-53 × KKU40	1.19^{ns}	-0.15^{ns}	1.99^{ns}	-0.86^{ns}	0.64^{ns}	-0.60^{ns}	-511 ns	130 ns	-0.25 ns
KKA-53 × Theis	1.86^{ns}	0.45^{ns}	13.29^{ns}	0.43^{ns}	-0.90^{ns}	5.50***	4793 ***	829 ***	-2.79 ***

*, **, and *** indicate that the GCA is significantly different from the mean at $\alpha \leq 0.05$, 0.01, and 0.001, respectively; ns = not significant

Conclusions

Heterosis in sweet sorghum was observed for several traits related to ethanol production, but overall, theoretical sugar yields of the hybrids were often not greater than that of inbred lines. However, hybrids have an advantage over inbreds in that seed is more easily produced and mechanically harvested using short male-sterile lines. Two female lines (KKA-139 and KKA-53) and one male (BJ248) showed positive GCA for theoretical sugar yield. These lines should be included in future hybrid breeding studies. For most traits, particularly biomass yield, stripped stalk yield, theoretical juice yield, and theoretical sugar yield, SCA effects were greater in magnitude than GCA effects, and environmental interaction was important. Overall, the hybrids KKA-11 × BJ248, KKA-11 × KKU40, KKA-139 × BJ248, KKA-14 × KKU40, and KKA-53 × Theis had positive SCA for sugar yield, and would be recommended for further testing in more locations. Hybrid KKA-11 × BJ248 had positive SCA for plant height, stalk diameter, stripped stalk yield, biomass yield, theoretical juice yield, and grain yield, although SCA for Brix was negative for this cross. In general, F_1 hybrids have advantages over pure lines except Brix values of F_1 hybrids were lower than pure lines. Therefore Brix should be the first target for further improvement in this sweet sorghum improvement program by fixing high Brix in both male and female parents.

Experiment field at NCSRC

Experiment field at KKU

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