RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
48 (1) 97-104, 2016

DIVERSITY OF CHARACTERISTICS ASSOCIATED WITH LODGING RESISTANCE IN SUGARCANE GERMPLASM

N. SINGKHAM[1], P. SONGSRI[1,2,*], P. JAISIL[2], S. JOGLOY[1,2], P. KLOMSA-ARD[3], N. JONGLANGKLANG[1,2] and A. PATANOTHAI[2]

[1] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand
[2] Northeast Thailand Cane and Sugar Research Center, Khon Kaen University, Khon Kaen 40002, Thailand
[3] Mitr Phol Innovation and Research Center, 399 Moo 1, Chumpae-Phukieo Road, Khoksa-ard, Phukieo, Chaiyaphum 36110, Thailand
[*]Corresponding author's email: patcharinso@kku.ac.th
Co-authors' email addresses: singkom24@gmail.com, pjaisil@gmail.com, sjogloy@kku.ac.th, peerayak@mitrphol.com, nuntawootjrk@gmail.com, aran@kku.ac.th

SUMMARY

Lodging is commonly occurred in sugarcane production, and reduced sugarcane productivity through lower biomass production and a reduction in cane quality. The objectives of this experiment were to investigate the indirect selection traits associated with lodging resistance in sugarcane to determine the genetic variation in non-lodging traits in sugarcane germplasm. A field experiment was conducted at Amphoe Nong Ruea, Khon Kaen, Thailand. The experiment was conducted on first ratoon crops during December 2012 to January 2013. Seventy-seven sugarcane lines were evaluated for determining the characteristic associated with lodging resistance. The result revealed that sugarcane lines were classified with stalk angle in 3 groups for lodging, moderate-lodging and non-lodging groups. MPT06-258 and MPT08-122 were high lodging resistance cultivars, which have high stalk weight, number stalk per hill, basal diameter, % fiber and CCS. Stalk height is indicator for indirect selection for lodging trait. This information would directly help in breeding selection for lodging resistance in sugarcane.

Key words: Breeding, lodging, erectness, *Sacharum spp.*

Key findings: Stalk height and erectness is indicator for indirect selection for lodging resistant trait. This information would help sugarcane breeders to select for lodging resistance.

Manuscript received: September 23, 2015; Decision on manuscript: January 28, 2016; Manuscript accepted: February 4, 2016.

Communicating Editor: Bertrand Collard

INTRODUCTION

Sugarcane cultivated species is the major source of sugar in the world. Sugarcane contributes around 70% of total sugar produced in the world (Contreras *et al*., 2009), the rest being produced from sugar beet and other sources. Sugarcane is a multi-product crop, every fraction of which economic use either as food, fodder, fuel or fiber and plays a major role in the rural economy (Scortecci *et al*., 2012).

Lodging commonly occurs in sugarcane production, and known to reduce the productivity of sugarcane through lower biomass production and a reduction in cane quality. Lodging of sugarcane significantly decreased fresh cane yield and commercial cane sugar (CCS), increased suckering and stalk deterioration (Wilson and Leslie, 1997; Singh *et al*., 2002; Berding and Hurney, 2005). Hence, the prevention of lodging in sugarcane can increase cane yield (11-15%), CCS (3-12%) and sugar yield (15-35%) (Singh *et al*., 2002). The main factors associated with lodging in sugarcane were the stalks and roots (Baker *et al*., 1998). Moreover, sugar cane lodging related to morphological and physiological characters such as cane height, stalk diameter, % fiber and stalk strength etc. (Berding and Hurney, 2005; Babu *et al*., 2009). Sugarcane breeding for lodging resistance was difficult to select lodging resistant lines, because the selection for this trait must be evaluated in the suitable area for the expression of lodging. Singh *et al*. (2002) reported that better grown crop of sugarcane were more lodge than that poorly grown crops. Therefore, the selection lodging resistance lines should be use indirect selection for lodging trait.

The better understanding of the traits related to lodging resistance in sugarcane and genetic diversity will be useful for lodging resistance selection in sugarcane. Therefore, the objectives in this experiment were to investigate the indirect selection traits associated with lodging resistance in sugarcane to determine the genetic variation in non-lodging traits in sugarcane germplasm.

MATERIALS AND METHODS

Field Experiment

Seventy-seven clones of sugarcane were evaluated for determining the characteristic associated with lodging resistance in the field condition at Amphoe Nong Ruea, Khon Kaen Province, Northeast of Thailand. The plant crop was conducted during November 2011-December 2012, while the first ratoon crop was done during December 2012-January 2013. All of the sugarcane germplasm was planted manually. A two-row plot with 8 m long and spacing of 1.3 m between rows was adopted. All plots were irrigated after planting, and were sprayed with a pre-emergence herbicide for weed control. Fertilizer application for each plot was based on soil analysis for both crops plant and first ratoon crops. Each plot for plant crop was harvested by manual in December 2012. The first ratoon crop was grown during December 2012 to January 2013.

Data collection

The data collection of sugarcane germplasm in first ratoon crop was recorded at the harvest. Data were recorded from the center two rows of each plot on percent germination at 12 months after emergence in first ratoon crop. Four stools for each plot were randomized for data collection, which the border plants in each plot were discarded. Leaf and stalk data were collected for 4 random stalks in each stool in each plot. Stalk height was measured from the ground to the last exposed dewlap (LED). Stalk diameter was taken at base, middle and top level of stalk. Stalk weight was determined from a 4 stalk sample at harvest. The angles of stalk for each stool for each genotype were recorded.

Four stalks for each plot were random to determine the commercial cane sugar (CCS) value (Klomsa-ard *et al*., 2013) as:

$$CCS = 3/2P\,[1-(F+5)/100] - B/2[1-(F+3)/100]$$

Where: F is fiber (%), B is the brix value (% of soluble solids) detected by reflectometer, and *P* is the pol value (apparent sucrose) detected by saccharimeter.

Statistical analysis

Analysis of variance for each character was carried out according to the procedures by Hoshmand (2006). Hierarchical agglomerative clustering was then performed for lodging character and agronomic traits, using the Ward criterion. All calculations were performed using JMP Pro software (version 10.0, SAS institute Inc., Chicago, IL, USA). Simple correlation analysis was used to determine the relationship among stalk angle, stalk height, stalk weight, stalk diameter, % fiber, brix and CCS.

RESULTS

Genetic variability

Mean comparison of 77 sugarcane cultivars for stalk weight, basal diameter, stalk number, stalk angle, stalk height, the commercial cane sugar (CCS), fiber (%) and Brix value were showed in Table 1. The results showed that a statistically significant genotypic effect for stalk weight character. The genotypes, MPT08-191, MPT06-258 and 02-2-194 had the highest stalk height and the values were 2740, 2733 and 2720 cm, respectively. Basal stalk diameter showed a highly significant difference in sugarcane cultivars. MPT08-36, MPT08-289 and MPT04-204 were had the highest basal diameter and the values were 36.9, 36.9 and 36.7 mm, respectively. Sugarcane genotypes were significantly different in brix, and MPT07-154, MPT08-122 and MPT06-362 had 23.4, 23.2 and 22.9, respectively. Percentage fiber showed a statistically significant difference in sugarcane. MPT08-80, MPT08-183 and MPT06-258 had the highest percent of fiber and the values were 14.1, 13.2 and 12.9%, respectively. Moreover, sugarcane cultivars showed a highly significantly difference in the commercial cane sugar (CCS) and MPT06-362, MPT07-154, KPK 98-40 had the highest CCS values (15.27, 15.26 and 14.88, respectively). The results showed a highly significant genotypic effect for stalk number. The genotype MPT08-80, LK92-11 and MPT08-171 had the highest stalk number and the values were 11.3, 10.5 and 10.00, respectively. There was a statistically significant difference for stalk angle and MPT06-166, K99-72 and MPT08-72 had the highest values (90 degree). Sugarcane lines showed a statistically significant difference for stalk height and MPT07-22, MPT06-258 and MPT07-111 had the highest stalk height (346.3, 345.0 and 341.7, respectively).

Table 1. Mean for stalk weight, basal diameter, stalk number, stalk height, brix, fiber and CCS of 77 sugarcane clones.

Clone	Stalk weight (g)	Basal diameter (mm.)	Stalk number (per hill)	Stalk angle (degree)	Stalk height (cm.)	Brix (%)	Fiber (%)	CCS (%)
MPT08-227	2103 g-r	32.0 f-t	5.8 i-m	85.0 a-d	236.5 n-w	21.27 c-q	11.65 b-k	12.71 a-n
MPT08-56	2297 c-l	32.6 c-s	6.0 h-l	78.8 a-d	283.0 cde	16.92 a’-c’	9.60 i-q	7.64 v-x
MPT08-276	1903 k-w	29.6 o-w	5.8 i-m	88.8 a	267.0 e-l	18.82 v-z	11.00 b-n	10.05 n-v
MPT08-141	1960 i-v	30.5m-w	5.5 j-n	85.0 a-d	253.0 f-s	19.12 t-z	10.05 d-p	9.37 q-v
MPT08-266	2080 g-s	32.4 e-s	2.8 r	87.5 ab	246.3 i-u	21.28 c-q	10.60 c-n	12.98 a-m
MPT08-186	2068 h-s	33.1 a-q	5.5 j-n	83.8 a-d	252.3 g-t	21.33 c-p	9.80 f-q	12.91 a-m
MPT08-301	1833 m-w	33.0 a-r	3.0 qr	88.8 a	227.0 q-z	19.99 m-x	9.80 f-q	12.19 b-p
MPT08-72	1665 r-y	30.7 k-w	5.0 k-p	90.0 a	213.7 w-a’	20.63 f-u	12.35 a-d	12.02 e-q
MPT08-247	2403 a-i	36.0 a-g	3.8 o-r	78.8 a-d	268.0 e-l	20.48 g-v	9.50 j-q	11.55 e-r
MPT08-188	2427 a-h	36.5 a-e	4.0 n-r	87.5 ab	226.0 r-z	19.08 t-z	11.45 b-l	9.53 p-v
MPT08-238	1883 l-w	34.4 a-m	6.0 h-l	82.5 a-d	234.7 p-w	18.20 y-b’	10.05 d-p	6.43 wx
MPT08-95	2418 a-h	32.3 f-s	4.0 m-r	73.8 def	275.3 efg	21.26 c-q	10.45 c-n	13.34 a-k
MPT08-48	2028 h-u	32.7 c-s	5.3 k-o	65.0 fgh	273.3 e-i	18.75 w-a’	10.00 d-q	8.67 s-w
MPT08-91	1793 o-w	28.0 t-w	5.7 i-n	85.0 a-d	250.0 g-t	20.31 j-x	12.05 a-h	10.61 l-t
MPT08-307	1813 n-w	34.5 a-m	4.5 l-q	85.0 a-d	165.0 d’	21.76 b-l	9.20 l-q	14.12 a-e
MPT08-195	2053 h-s	36.0 a-g	5.0 k-p	82.5 a-d	207.5 x-b’	20.76 e-t	9.10 l-q	11.23 f-s
MPT08-82	2630 a-e	35.3 a-j	5.5 j-n	85.0 a-d	244.7 j-u	19.06 t-z	8.60 n-q	10.99 h-t
MPT08-50	1817 n-w	31.0 k-v	5.0 k-p	85.0 a-d	230.8 q-y	16.31 a’b’	9.85 e-q	7.71 v-x
MPT08-3	2293 c-l	33.5 a-q	3.7 o-r	85.0 a-d	226.3 r-z	20.32 i-x	9.95 d-q	12.25 b-o
MPT08-130	2203 e-p	29.9 n-w	4.7 k-q	85.0 a-d	262.0 e-o	21.97 a-j	10.40 d-n	13.92 a-f
MPT08-289	1958 i-v	36.9 ab	5.3 j-o	87.5 ab	188.0 b’-d'	21.76 b-l	10.10 d-p	14.00 a-e
MPT08-101	1570 v-z	31.0 k-v	3.3 pqr	78.8 a-d	178.3 c’d’	22.22 a-f	9.55 i-q	14.73 a-d
MPT08-36	1940 j-v	37.0 a	5.3 k-o	81.3 a-d	226.7 q-z	19.47 s-y	9.10 l-q	10.91 i-t
MPT08-144	1868 l-w	33.1 a-q	5.3 k-o	81.3 a-d	243.5 k-u	21.52 b-o	7.90 opq	11.93 e-r
MPT08-180	2430 a-h	29.8 n-w	5.3 k-o	81.7 a-d	269.7 e-k	20.58 f-u	9.55 i-q	11.95 e-r
MPT08-254	2267 d-m	29.6 o-w	4.3 m-r	83.8 a-d	249.5 g-t	21.13 d-s	12.10 a-g	12.05 d-p

Clone	Stalk weight (g)	Basal diameter (mm.)	Stalk number (per hill)	Stalk angle (degree)	Stalk height (cm.)	Brix (%)	Fiber (%)	CCS (%)
MPT08-191	2740 a	36.6 a-d	7.0 g-j	82.5 a-d	232.7 q-x	20.13 k-x	8.60 n-q	11.93 e-r
MPT08-122	2447 a-h	32.6 c-s	5.3 k-o	82.5 a-d	232.3 q-x	23.19 ab	11.00 b-n	14.74 a-d
MPT08-183	2117 g-q	29.4 p-w	3.5 p-r	85.0 a-d	251.8 g-t	22.43 a-e	13.15 ab	13.65 a-h
MPT08-80	1938 j-v	28.8 r-w	11.3 a	89.3 a	236.3 o-w	21.53 b-o	14.10 a	11.69 e-r
MPT08-171	2373 a-j	32.5 d-s	10.0 a-c	85.0 a-d	226.7 q-z	21.19 c-r	10.50 c-n	12.64 a-n
MPT04-121	1473 w-z	28.6 s-w	8.7 c-f	87.5 ab	247.8 h-t	22.59 a-d	10.65 c-n	8.57 t-w
K99-72	1593 u-z	33.1 a-q	5.7 i-n	90.0 a	237.8 m-w	21.74 b-l	10.95 b-n	11.91 e-r
MPT04-169	1568 v-z	31.2 i-v	3.7 o-r	52.5 ij	225.8 s-z	21.49 b-o	11.95 a-i	12.17 c-p
MPT04-204	2340 a-k	36.7 a-c	4.8 k-p	80.7 a-d	242.0 l-v	21.44 c-o	10.15 d-p	12.70 a-n
MPT04-303	2303 b-l	34.5 a-m	3.7 o-r	86.3 a-d	262.0 e-o	18.65 x-a’	10.05 d-p	9.83 o-v
MPT04-509	2033 h-u	34.7 a-l	6.3 h-k	37.5 klm	248.3 g-t	21.74 b-l	10.35 d-n	13.42 a-j
LK92-11	1803 o-w	32.6 c-s	10.5 ab	84.0 a-d	216.0 v-a’	21.05 d-s	11.20 b-m	11.12 g-t
MPT04-657	2080 g-s	32.4 d-s	6.3 h-k	80.0 a-d	253.7 f-q	21.60 b-n	10.45 c-n	13.41 a-j
MPT04-55	1650 s-y	31.3 i-v	5.0 k-p	78.5 a-d	267.3 e-l	20.06 l-x	12.25 a-e	10.99 h-t
MPT04-98	2520 a-g	31.6 h-u	6.3 h-k	75.0 b-f	274.3 e-h	19.65 p-y	10.75 b-n	11.20 g-s
MPT04-380	2315 a-l	36.1 a-g	3.7 o-r	63.3 fgh	229.7 q-z	21.70 b-m	10.90 b-n	13.26 a-l
KK 3	1190 z	24.1 x	8.0 d-g	77.5 a-e	202.3 z-b’	21.76 b-l	12.15 a-f	13.05 a-m
MPT04-467	1318 xyz	26.9 wx	8.0 efg	78.5 a-d	246.3 i-u	22.10 a-h	11.20 b-m	11.77 e-r
MPT04-298	1778 p-w	32.9 a-r	6.0 h-l	86.5 abc	225.0 t-z	21.35 c-p	10.25 d-o	12.88 a-m
MPT04-257	2063 h-s	33.8 a-n	5.3 j-o	5.0 o	273.0 e-i	22.01 a-j	10.35 d-n	13.77 a-g
MPT04-212	2260 d-n	31.2 i-v	3.5 pqr	18.8 n	238.3 m-w	22.31 a-f	9.80 f-q	13.19 a-l
Tby 26-1802	2043 h-t	33.3 a-q	4.8 k-p	77.5 a-e	279.3 def	17.77 z-c’	10.25 d-o	9.29 r-v
94-2-254	2028 h-u	34.4 a-m	7.0 g-j	80.0 a-d	267.3 e-l	20.41 h-w	9.50 j-q	11.04 h-t
Kps 00-103	1597 t-z	29.9 n-w	5.7 i-n	85.0 a-d	260.0 e-p	19.60 q-y	10.75 b-n	11.43 e-r
02-2-194	2720 abc	33.2 a-q	4.0 m-r	81.3 a-d	260.0 e-p	20.35 i-w	10.20 d-o	11.85 e-r
K 01-10	1823 m-w	31.5 h-u	5.8 i-m	66.3 efg	264.7 e-m	19.60 q-y	8.95 m-q	11.42 e-r
Kps 01-25	1880 l-w	34.8 a-k	4.0 n-r	73.8 c-f	251.0 g-t	19.51 r-y	10.80 b-n	10.75 j-t
KPK 98-40	1650 s-y	30.6 l-w	4.0 n-r	58.8 ghi	205.5 y-b’	22.17 a-g	7.60 q	14.88 ab
MPT06-26	1250 yz	26.9 wx	7.5 fgh	83.3 a-d	166.5 d’	20.36 i-w	11.30 b-m	11.91 e-r
MPT06-95	1543 v-z	33.0 a-r	5.5 j-n	87.5 ab	225.0 t-z	21.71 b-m	11.05 b-m	13.31 a-k
MPT06-105	2717 abc	35.6 a-h	2.7 r	55.0 hij	301.3 bcd	21.86 a-k	11.80 a-j	12.89 a-m
MPT06-139	1907 k-w	29.7 n-w	4.3 m-r	75.0 b-f	245.5 j-u	21.95 a-j	11.30 b-m	13.61 a-i
MPT06-144	1658 r-y	34.4 a-m	10.0 abc	75.0 b-f	199.0 a’-c’	20.06 l-x	9.50 j-q	12.16 c-p
MPT06-166	1910 k-w	36.2 a-f	7.0 g-j	90.0 a	253.3 f-r	19.71 p-y	11.10 b-m	11.48 e-r
MPT06-258	2733 ab	33.6 a-o	4.7 k-q	77.5 a-e	345.0 a	21.66 b-n	12.85 abc	13.31 a-l
MPT06-344	1817 n-w	35.4 a-i	7.0 g-j	81.3 a-d	220.5 u-a’	21.35 c-p	9.70 g-q	13.47 a-i
MPT06-362	2083 g-s	31.9 g-t	6.3 h-k	73.8 def	262.0 e-o	22.90 abc	9.30 k-q	15.27 a
MPT06-367	1637 s-y	27.6 u-x	3.5 pqr	35.0 lm	286.7 cde	20.74 e-t	12.25 a-e	12.21 b-p
MPT06-413	2583 a-f	32.8 b-r	5.8 i-m	75.0 b-f	263.7 e-n	19.94 n-x	11.95 a-i	11.90 e-r
MPT06-578	1720 q-x	31.2 j-v	4.5 l-q	41.3 kl	314.3 b	21.34 c-p	12.10 a-g	12.93 a-m
MPT07-306	1720 q-x	30.6 l-w	9.3 b-e	83.8 a-d	234.5 p-w	21.34 c-p	7.75 pq	12.64 a-n
MPT07-258	2280 d-l	31.3 i-v	6.0 h-l	80.0 a-d	245.5 j-u	19.83 o-y	9.55 i-q	10.07 n-v
MPT07-1	1945 j-v	34.3 a-m	9.5 bcd	78.8 a-d	260.5 e-p	15.84 d’	9.65 h-q	5.95 x
MPT07-71	2228 e-o	32.6 c-s	5.5 j-n	87.5 ab	304.8 bc	20.58 f-u	10.80 b-n	9.78 o-v
MPT07-208	2683 a-d	33.5 a-p	5.0 k-p	85.0 a-d	271.0 e-j	17.24 a’-d’	11.15 b-m	7.85 u-x
MPT07-152	2400 a-i	32.7 c-s	5.3 j-o	85.0 a-d	261.5 e-p	18.93 u-z	10.05 d-p	10.39 m-u
MPT07-22	2223 e-p	29.8 n-w	3.7 o-r	20.0 n	346.3 a	20.34 i-x	12.35 a-d	10.65 k-t
MPT07-154	2207 e-p	32.3 f-s	5.0 k-p	46.7 jk	324.0 ab	23.44 a	10.80 b-n	15.26 a
MPT07-111	1660 r-y	29.3 q-w	4.3 l-r	73.8 c-f	341.7 a	21.74 b-l	9.70 g-q	12.84 a-m
MPT07-516	2175 f-p	27.3 v-x	4.0 n-r	27.5 mn	312.5 b	21.15 d-s	10.20 d-o	13.40 a-j
MPT07-665	2035 h-u	31.5 h-u	7.3 f-i	37.5 klm	313.7 b	22.05 a-i	9.85 e-q	14.80 abc
Mean	2031.29	32.25	5.53	74.61	251.34	20.64	10.50	11.85
F-test	**	**	**	**	**	**	**	**
C.V. (%)	12.36	7.12	17.66	9.45	6.14	3.53	9.25	9.08

*, ** significant at $P \leq 0.05$ and 0.01 probability levels, respectively.
Means in the same column followed by the same letter (s) are not significantly different (at $P = 0.05$) by DMRT

Cluster analysis of genetic relationship

Dendrogram showing genetic relatedness of 77 varieties of sugarcane for stalk weight, basal diameter, stalk number, stalk angle, stalk height, brix, fiber and CCS. Five main clusters (A to E) were formed (Figure 1). Two ways clustering method was Ward's cluster analysis based on stalk weight, basal diameter, stalk number, stalk angle, stalk height, brix, fiber and CCS. Sugarcane lodging was classified with stalk angle or the degree of stalk angle. The non-lodging group consists of 62 cultivars, which had 70 - 90 degrees of stalk angle. Moderate-lodging group composed of 6 cultivars, which had 50 - 70 degrees of stalk angle. The lodging group composed of 9 cultivars, which had 0 - 50 degrees of stalk angle.

Correlation between lodging characteristics

The relationship between lodging characters is important for sugarcane breeding program. The correlation of 11 characters for 77 sugarcane cultivars was showed in Table 2. The results showed that stalk angle or degree of stalk angle was positive related to basal diameter (r = 0.25; $P \leq 0.01$). In contrast, stalk angle was a negative related to stalk height (r = -0.45; $P \leq 0.01$), shoot number per hill (r = -0.21; $P \leq 0.01$), brix (r = -0.29; $P \leq 0.01$) and pol (r = -0.29; $P \leq 0.01$). Moreover, there was not a significant correlated between stalk angle and fiber content.

DISCUSSION

From the experiment, sugarcane germplasm resources were a statistically significant difference in all traits, which was used to classify the genetic resources. Baker *et al*. (1998) reported crop lodging response to root and shoot system. The previous study indicated that the lodging in wheat related to root – soil system failure, which depend on the stem base buckled (Graham, 1983). Moreover, the strength of stem, stem diameter, stem height, stalk number per hill, stalk angle and leaf area were related to lodging process (Babu *et al*., 2009; Sinclair *et al*., 2005).

Our results reported that stalk angle was the index for lodging in this experiment. We classified 3 groups of sugarcane germplasm for non-lodging, moderate-lodging and lodging. Each group had high stalk weight, stalk height, percent of fiber, stalk number per hill and stalk diameter (Figure 2). The result found that lodging and non-lodging group had the same pattern, showing that stalk weight, stalk height, percent of fiber, stalk number per hill, stalk diameter was closely in both groups.

For the relationship between lodging traits and sugarcane cultivars, stalk height were related with lodging than other traits. It is interesting to note here that some non-lodging cultivar had low stalk height than lodging cultivars (Figure 2). Berding and Hurney (2005) suggested that using clones with reduced stalk height can reduce lodging. However, non-lodging sugarcane increased yield production by 11-15% of total yield and also decreased CCS by 3-12% and sugar by 15-35%, respectively at final harvest (Singh *et al*., 2002). Berding and Hurney (2005) concluded that lodged sugarcane at final harvest reduced sugar production and CCS because of the new suckering which occurred. This result might also indicate that lodging, moderate-lodging and non-lodging groups were rather similar in case of CCS. Bhat *et al*. (1985) found that the relationship between percent of fiber and sugarcane bark strength were statistically significant. High fiber content in sugarcane would reduce lodging because of high stalk strength (Babu *et al*., 2009). From the result, fiber percentage were not related with lodging because lodging and non-lodging group were rather similar value. In contrast, lodging group had high fiber, indicating that there had the genetic diversity for lodging trait.

There were not significant differences for CCS between lodging and non-lodging groups due to field management and the effect of ratoon crop. Singh *et al*. (2002) reported that field management affect to lodging in sugarcane. Moreover, lodging resistance cultivar might be grown in fertile soil and good management such as low cutting and make the scaffolding, which can reduce lodging procedure.

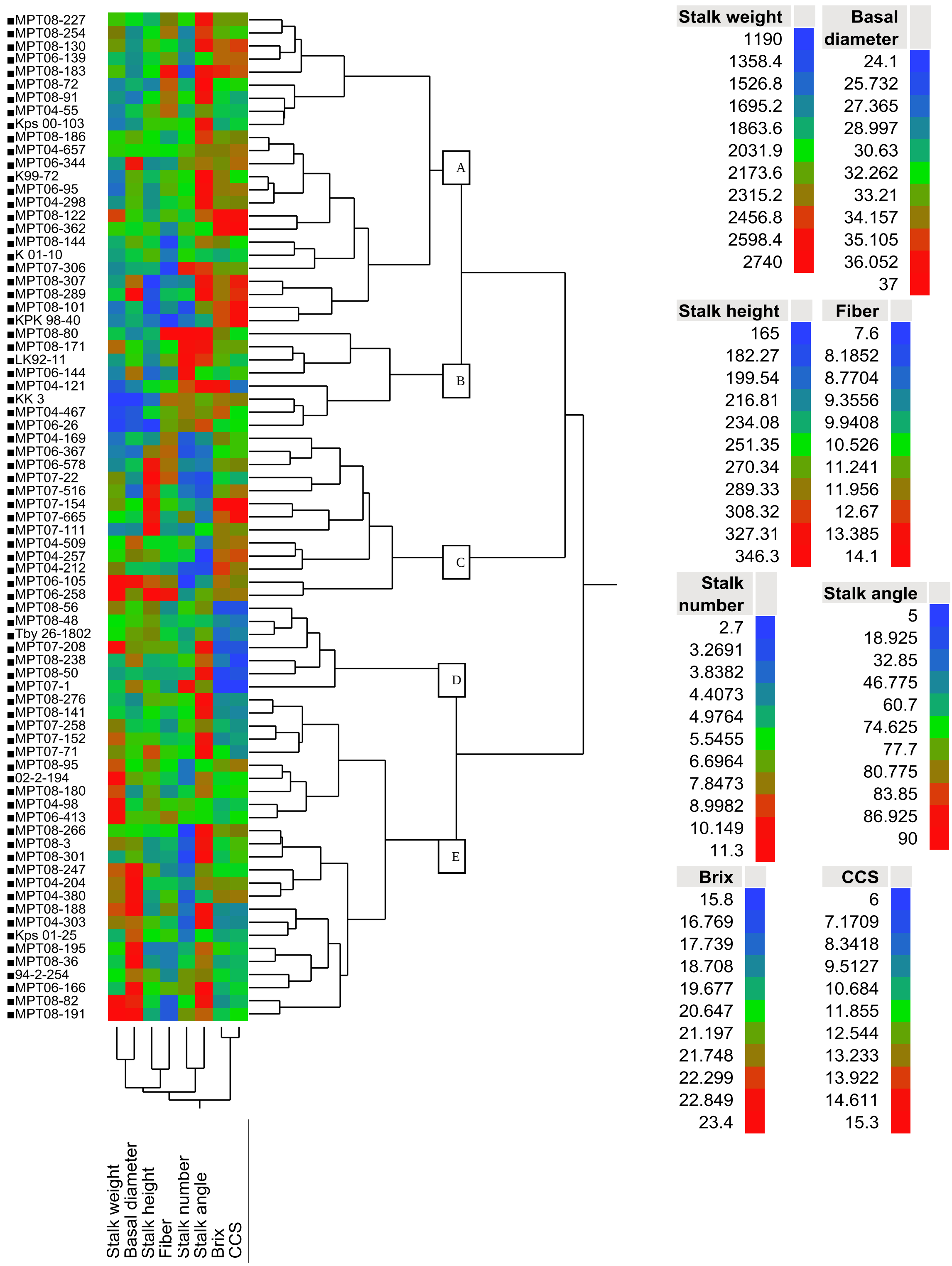

Figure 1. Dendrogram showing genetic relatedness of 77 varieties of sugarcane for stalk weight, basal diameter, stalk number, stalk angle, stalk height, brix, fiber and CCS. Five main clusters (A to E) were formed. Two ways clustering method was Ward's cluster analysis based on stalk weight, basal diameter, stalk number, stalk angle, stalk height, brix, fiber and CCS (scale: Distance scale)[a]

[a] Cluster together columns as well as rows; the columns must be measured on the same scale.

Table 2 The correlations between stalk angle (SA), basal diameter (BD), middle diameter (MD), top diameter (TD), number of internode (NI), stalk height (SH), shoot number per hill (SH), stalk weight (SW), Brix, CCS, fiber and pol.

Traits	BD	MD	TD	NI	SH	SH	SW	Brix	CCS	Fiber	Pol
SA	0.06	0.25*	-0.12	-0.16	-0.41**	-0.21*	-0.06	-0.27*	-0.29*	-0.05	-0.29*
BD		0.58**	0.31**	0.14	-0.10	-0.12	0.55**	-0.17	-0.07	-0.28*	-0.11
MD			0.52*	0.06	-0.30**	-0.09	0.49**	-0.36**	-0.17	-0.26*	-0.24*
TD				0.11	-0.09	-0.16	0.44	-0.18	-0.04	-0.07	-0.08
NI					0.40**	-0.30**	0.41	0.00	0.04	0.03	0.03
SH						-0.21	0.39**	-0.06	-0.10	0.19	-0.08
SH							-0.26	-0.06	-0.19	-0.01	-0.15
SW								-0.17	-0.10	-0.07	-0.12
Brix									0.87**	0.13	0.93**
CCS										0.02	0.99**
Fiber											0.12

*, ** Significant at $P \leq 0.05$ and 0.01 probability levels, respectively.

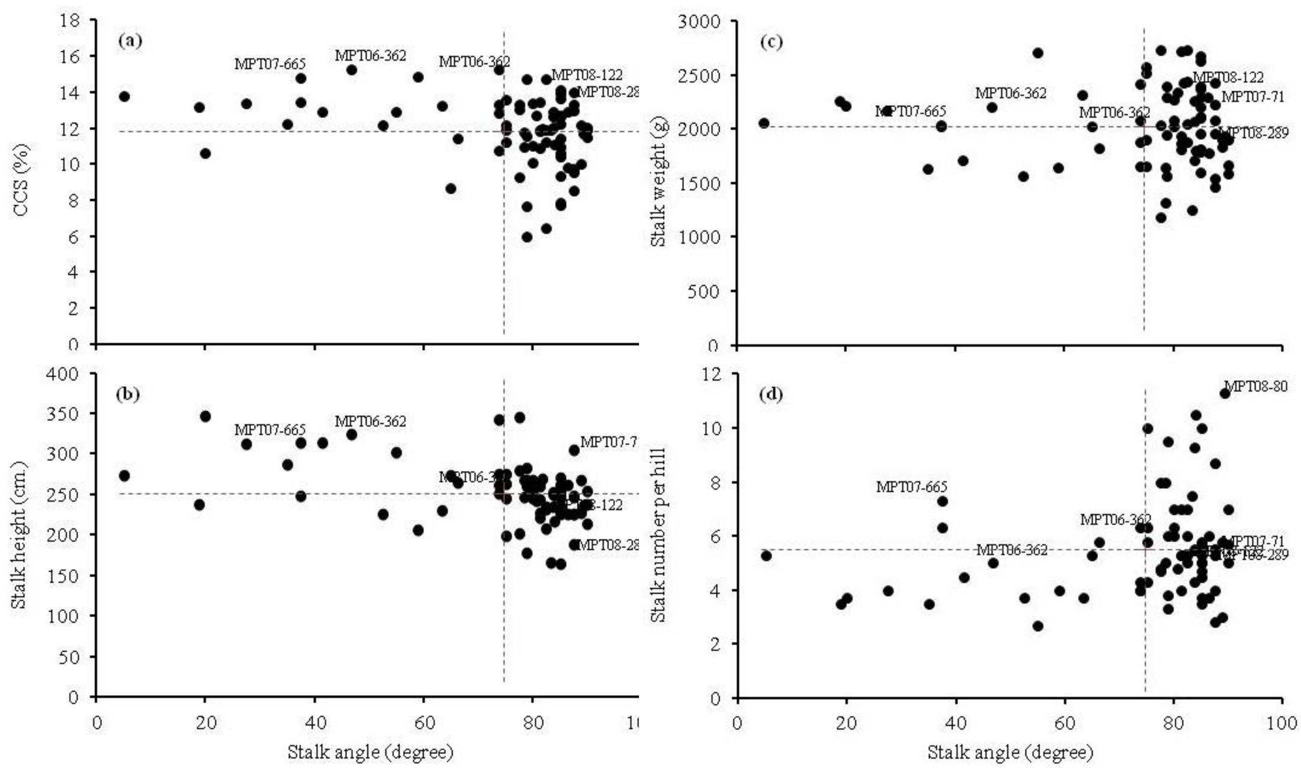

Figure 2. Stalk angle and CCS (a), stalk height (b), stalk weight (c),and stalk number per hill (d) of 77 sugarcane clones.

CONCLUSION

The sugarcane lines in this study were classified in 3 groups with lodging, moderate-lodging and non-lodging. Stalk height was an indicator for lodging. Finally, MPT06-258 and MPT08-122 had high lodging resistance traits and had high stalk weight and CCS. Therefore, this result would help developing sugarcane breeding programs for lodging resistance and good agronomic traits.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support of the Khon Kaen University and support in part by the Northeast Thailand Cane and Sugar Research Center, and the Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen University. Acknowledgements also extended to Mitr Phol Innovation and Research Center, Mitr Phol Group for providing the sources of sugarcane germplasm. Acknowledgment is extended to the Thailand Research Fund (TRF), Khon Kaen University (KKU) and the Faculty of Agriculture Khon Kaen University for providing financial support for manuscript preparation activities.

REFERENCES

Babu C, Koodalingam K, Natarajan US, Shanthi RM, Govindaraj P (2009). Assessment of rind hardness in sugarcane (*Sacharum* Spp. Hybrids) genotypes for development of non-lodging erect canes. *Advances in Biological Res.* 3(1-2): 48-52.

Baker CJ, Berry PM, Spink JH, Sylvester-Bradley R, Griffin JM, Scott RK, Clare RW (1998). A method for the assessment of the risk of wheat lodging. *J. Theor. Biol.* 194: 587-603.

Berding N, Hurney AP (2005). Flowering and lodging, physiological-based traits affecting cane and sugar yield. What do we know of their control mechanisms and how do we manage them? *Field Crops Res.* 92: 261–275.

Bhat SR, Raman K, Tripathi BK (1985). Association analysis of rind hardness and fibre content in sugarcane. *Indian J. Genet.* 45(2): 310-315.

Blackburn FC (1984). Sugar-cane. The Print House (Pte) Ltd: Singapore.

Barnes AC (1974). The sugar cane. Great British by Billing & Sons Ltd., London. pp. 28.

Esechie HA, Maranville JW, Ross WM (1977). Relationship of stalk morphology and chemical composition to lodging resistance in sorghum. *Crop Sci.* 17(4): 609-612.

Esechie HA (1983). Relationship between lodging, certain morphological characters and yield of grain sorghum (*Sorghum bicolor* L. Moench). *J. Agric. Sci.* 101(3): 669-673.

Fauconnier R (1993). Sugarcane. Macmillan: London. pp. 140.

Flint-Garcia SA, Jampatong C, Darrah LL, McMullen MD (2003). Quantitative trait locus analysis of stalk strength in four maize populations. *Crop Sci.* 43: 13-22.

Graham JA (1983). Crop lodging in British wheats and barleys. University of Reading.

Jackson PA (2005). Breeding for improved sugar content in sugarcane. *Field Crops Res.* 92: 277-290.

Kimbeng CA, Cox MC (2003). Early generation selection of sugarcane families and clones in Australia: a review. *J. Am. Soc. Sugar Cane Technol.* 23: 20-39.

Maranville JW, Clegg MD (1983). Morphological and physiological factors associated with stalk strength. Sorghum Root and Stalk Rots. A critical review. International Crops Research Institute for the Semi-Arid Tropics. pp. 111-118.

Ray M, Moore PH, Wu KK, D’Hont A, Glaszmann JC, Tew TL, Mirkov TE, Da Silva J, Jifon J, Rai M, Schnell RJ, Brumbley SM, Lakshmann P, Comstock JC, Paterson AH (2005). Sugarcane improvement through breeding and biotechnology. *Plant Breed. Rev.* 27: 15-118.

Sinclair TR, Gilbert RA, Perdomo RE, Shine JM, Powell G, Montes G (2005). Volume of individual internodes of sugarcane stalks. *Field Crops Res.* 91: 207-215.

Singh G, Chapman SC, Jackson PA, Lawn RJ (2002). Lodging reduces sucrose accumulation of sugarcane in the wet and dry tropics. *Aust. J. Agric. Res.* 53: 1183-1195

Takagi H, Sato M, Matsuoka M (2005). A guidebook for sugarcane in Japan. Japan International Reseach Center for Agricultural Sciences (JIRCAS) and Japanese Society of Sugar Cane Technologists (JSSCT). Shonan Sugar Manufacturing Co. Ltd., Okinawa, Japan. pp. 121.

White WH, Tew TL, Richard Jr EP (2006). Association of sugarcane pith, rind hardness, and fiber with resistance to the sugarcane borer. *J. Am. Soc. Sugar Cane Technol.* 26:87-100.