EVALUATION OF LODGING RESISTANCE IN SUGARCANE (*SACCHARUM SPP. HYBRID*) GERMPLASM RESOURCES

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Abstract. In order to observe the performance of lodging-related traits, evaluate the lodging-resistant ability of different combinations of sugarcane, a field experiment was conducted in 2018. Thirty sugarcane combinations were used as the materials, and the lodging grade, fracture resistance force, basal stem diameter, middle stem diameter and brix were investigated. With the data of lodging classification, the lodging resistance index was established. It was found that the lodging resistance index was significantly and positively correlated with the ratio of basal and middle stem diameters and brix. A cluster analysis was conducted, for the thirty sugarcane combinations by the lodging resistance index, which showed sixteen were lodging resistant, thirteen half-lodging, and two complete-lodging.

Keywords: *lodging resistance, combination, stem diameter, fracture resistance force, index*

Introduction

Sugarcane (*Saccharum spp. hybrid*) is the largest sugar crop in China and the world, during the 2017/2018 milling season, the planting area was 1.38 million ha and the sugar yield was 10.48 million tones in China. Guangxi is the first in sugarcane planting area, sugar yield, and economic benefit in Chinese sugar industry (Li et al., 2010). Due to the tall plant and large biomass above ground, lodging occurs very common, which seriously affects the yield and sucrose content in cane, in some areas, the cane yield was reduced by 10% to 20% in light, and more than 50% in severe. The sucrose content was reduced by 15% to 35%, and the number of millable canes was reduced by 0.8 stalks/m² (Li et al., 2018; Singh et al., 2002). Meanwhile, lodging reduces the quality of mechanical harvesting, results in more harvesting loss, and increases broken rate of stools by 24.8% on average, which seriously hinders the popularization and application of machine harvest in sugarcane (Li, 2010; Mo, 1979) as well as the development of sugarcane industry (Liu and Fan, 2011; Zhang et al., 2010). There have been a lot of research about lodging resistance evaluation of germplasm resources for other crops, such as rice, maize, wheat, etc. (Wang et al., 2014; Kamran et al., 2018; Piñera-Chavez et al., 2016). Up to day, however, there has been no perfect evaluation method for sugarcane lodging at home and abroad, and very few reports about sugarcane lodging research could be referred. Considering the changes of climatic and ecological regions and the status of main cultivars, it is necessary to carry out comprehensive and specific

evaluation and research on lodging resistance of different sugarcane genotypes and the mechanisms in sugarcane lodging resistance (Kimbeng et al., 2000; Singh et al., 1999). This study was done by using thirty sugarcane combinations as materials to study the features of sugarcane lodging, establish classification standards for sugarcane lodging, and evaluate the lodging-resistant ability of the combinations, in order to provide a reference for selection of lodging-resistant parent and varieties in sugarcane.

Materials and methods

Plant materials

The tested materials were the seedlings from Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, Nanning in 2017. Thirty combinations were randomly selected, and the sugarcane variety ROC22 was used as control (*Table 1*). GT and SWS parents were from Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences. YT and ZZ parents were from Guangzhou Sugarcane Industry Research Institute. YZ and DZ parents were from Sugarcane Research Institute of Yunnan Academy of Agricultural Sciences. CP parents were from USDA Canal Point Sugarcane Field Station. FN, LC and ROC parents were from Fujian Agriculture and forestry university, Sugarcane Research Center of Liucheng and Taiwan Sugarcane Research Institute. C1, Co, FR, PR and NongL were imported from Brazil, Franch, Puerto Rico and Japan, respectively.

Table 1. *Sugarcane combinations tested*

No.	Combination	No.	Combination
142	CP07-1618×YG22	975	GT05-ym3×LC03-1137
229	GT04-112×YC90-33	977	YT94-128×GT09-1163
283	GT06-3283×LT07-95	981	SWS09-001×CP92-1641
289	NongL8×GT09-1009	989	C1-2003×YZ95-128
327	GT04-1023×FN39	1124	GT02-761×YF90-95
370	CP07-1618×FN39	1245	GT01-25×CP09-4707
371	CP07-1618×LC03-1137	1252	GT05-3661×CP09-4256
381	GT05-wm48×GT07-229	Y12	ROC28×YT00-236
399	Co1001×GT10-2018	Y44	YT00-318×YT93-159
430	YZ99-596×GT10-2018	Y50	YT01-71×DZ93-88
506	GT06-1264×YT96-833	Y57	YT91-976×ROC23
564	GT02-761×YC07-71	Y65	YT93-159×YC07-71
593	GT06-3283×YZ06-80	Y70	YT94-128×ROC22
643	GT02-901×GT06-178	Y86	ZZ33×GT92-66
670	CP00-1630×GT06-1184	ROC22	ROC5×69-463
875	FR93-865×PR83-1248		

Experimental site

The experiment was carried out in Dingdang base of Sugarcane Research Institute Guangxi Academy of Agricultural Sciences in Long'an County. The soil was neutral sandy loam.

Experiment design

The seeds of the tested combinations were sowed in late March, 2017, and the seedlings were transplanted to nursery cups in the middle of April when they had two to four leaves. On June 15th, they were planted in the field. Sixty nine individual plants were randomly selected in each combination. Repeated planting was carried out for 3 times in randomized block design. Each plot contained one row of 7 m long, and the space between rows was 1.2 m. Twenty three plants were planted in each plot. Compound fertilizer (N:P:K = 8:6:6) 750 kg/ha was applied as the base fertilizer at the time of planting and urea 75 kg/ha was dressed at tillering stage.

Investigation index and method

From November to December, the resistance grade, lodging resistance index, fracture resistance, basal stem diameter, middle stem diameter, and brix were estimated by measuring 21 seedlings in each plot excluding the first and last seedlings to avoid the marginal effect in each row.

Resistance grade: It was estimated by referring to the partition method of Hao et al. (2008) with modification. The classification was done based on the lodging angle formed by the link between the top and the base of the stem, and the perpendicular line of the ground (Table 2).

Lodging resistance index (LRI): It was estimated according to the method of Li et al. (2012) and Xie et al. (2009). The equation is as follows:

$$LRI = \sum(g_i \times n_i) / N \times 100\% \quad (\text{Eq.1})$$

where n is the number of lodging stalks in a lodging grade, g is the lodging grade, and N is the total number of stalks investigated.

Stem diameter: The middle parts of basal and middle stem internode were measured with vernier caliper at mature stage.

Brix: Cane juice was extracted and measure with ATAGO handheld saccharimeter at mature stage.

Fracture resistance force: Ten upright and uniform plants were selected in each row, not including the plants on the sides. A PROSTRATETESTER DIK-7401 was kept vertically to the middle of the stem and push it hard to the plant to form a 45° included angle. The data showing on the prostrate tester were recorded.

Table 2. The grading standard of sugarcane lodging resistance in field

Lodging grade	Lodging angle
Grade 1	> 60°
Grade 2	30-60°
Grade 3	0-30°

Data analysis

The data were processed by Excel 2010 and subjected to ANOVA, and mean values were separated using Duncan's multiple range test. All statistical analyses were performed using the DPS 14.15 statistical package. The correlation between

combinations and lodging indexes were evaluated using Person correlation analysis. The lodging resistance index was used for cluster analysis which was carried out with the method of the distance of χ^2 and sum of squares of deviation. The grading standard of sugarcane lodging resistance was made by the observation of the sugarcane lodging and relevant research results (*Table 3*).

Table 3. *The grading standard of sugarcane lodging resistance*

Resistance grade	Lodging resistance index	Lodging level
Grade 1	1.00-1.60	High lodging
Grade 2	1.61-2.30	Middle lodging
Grade 3	2.31-3.00	Erect

Results

Relationship between different agronomic traits and resistance grade

It data in *Table 4* showed that the differences were significant in different lodging types for all the agronomic traits. The differences in brix in the erect, half lodging and complete lodging types suggested that the impact of lodging on brix was salient, and lodging would certainly reduce the brix in cane juice. The basal and middle stem diameters also significantly and negatively affected sugarcane lodging. The larger the stem, the higher the lodging resistance was, regardless of middle or basal part. The ratio between basal and middle stem diameter was an important index. Obviously, the stem with consistency from top to base possesses excellent lodging resistance. The stem with thin base and thick middle parts was easy to get lodging.

Table 4. *The relationship of different agronomic traits and lodging*

Type	Brix (°BX)	Basal stem diameter (cm)	Middle stem diameter (cm)	Ratio of middle and basal stem diameter
Erect	19.8±0.9 a	237±21 a	236±20 a	1.00±0.05 a
Half lodging	19.6±1.0 b	225±17 b	231±17 b	0.98±0.05 b
Complete lodging	19.3±1.2 c	206±18 c	219±19 c	0.94±0.05 c

Data in the table are the means of three replicates. Different low case letters in the same column represent the significant difference at 5% in Duncan's multiple range test

The resistance force test was not effective in this experiment. As shown in *Table 5*, the differences in repetitions were very significant, but those in combinations were not significant.

Table 5. *The relationship of resistance force and different combinations in sugarcane*

Item	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Repetition	2	307.5	153.8	14.85	0.000007**
Combination	30	471.9	15.7	1.52	0.0876
Residuals	56	579.7	10.4		

** represent the significance at 1% levels

Analysis on relevance between agricultural traits and lodging resistance index

The lodging index resistance and the diameters of basal and middle stem were highly significantly and positively correlated ($r = 0.419^{**}$ and 0.356^{**}), indicating the thicker the stem was, the more lodging resistant the plant was. The lodging resistance index was significantly and positively correlated with the brix, suggesting that erect stalks had higher sugar content in cane. The lodging resistance index showed significantly positive correlation ($r = 0.201^{*}$ and $r = 0.232^{*}$) with the ratio of middle and basal stem diameter, indicating that the sugarcane genotypes with uniform stem were more lodging resistant. Though the correlation coefficients were moderate, they were significant in this study. The larger the ratio of middle and basal stem diameter was, the higher lodging resistance the sugarcane genotypes possessed (*Table 6*).

Table 6. Correlation coefficients between different traits

Correlation coefficient	Lodging resistance index	Resistance force	The ratio of middle in basal stem diameter	Brix	Basal stem diameter	Middle stem diameter
Lodging resistance index	1					
Resistance force	-0.02	1				
The ratio of middle in basal stem diameter	0.201*	-0.037	1			
Brix	0.232*	0.052	-0.168	1		
Basal stem diameter	0.419**	0.294**	0.432	0.093	1	
Middle stem diameter	0.356**	0.223*	-0.049	0.19	0.87	1

* and ** represent the significance at 5%, and 1% levels, respectively

Cluster analysis

Systematic cluster analysis was done based on the lodging resistance index, and the results were shown in *Figure 1*. The 30 tested combinations were divided into three categories, among them, 16 were in level 3, 13 in level 2, and 2 in level 1 (*Table 7*). GT and YT parents were accounted for 56% and 44% in level 3 respectively, and CP parents were accounted for 30% in level 2. The control variety ROC 22 belonged to the middle lodging type was classified in level 2 in this study, which was in line with its performance in commercial production.

Discussion

Three or more classifications were established according to the angle in other crops (Wang et al., 2015; Stamp and Kiel, 2010; Nakajima et al., 2008). By far, there has been no confirmed classification for lodging in sugarcane. In this study, the lodging of 30 sugarcane was classified into three levels, that is, level 1 (lodging), level 2 (half-lodging) and level 3 (erect) referring to other crops and sugarcane production reality. Meanwhile, the lodging index was brought up, and supported by the test data. The index could be used to judge the capability of lodging resistance of sugarcane rapidly. In the past, many sugarcane breeders had been deducing the lodging resistance trait by visual observation, and deducing whether the sugarcane was lodging resistant or not according to the approximate growth of sugarcane stalks in the field. But it was difficult for breeders to distinguish the status of some sugarcane genotypes which looked either like

lodged or erect, unless they were all erect or lodged. If the plants of a clone tended to lodging, which would be classified as complete lodging. With the lodging resistance index established in this study, we can quickly determine the lodging resistance of a clone and greatly improve the efficiency of sugarcane breeding.

Figure 1. Clustering of lodging for different sugarcane combinations

Table 7. The lodging level of different combinations

No.	Combination	Level	No.	Combination	Level
977	YT94-128×GT09-1163	3	ROC22	ROC5×69-463	2
Y65	YT93-159×YC07-71	3	Y57	YT91-976×ROC23	2
593	GT06-3283×YZ06-80	3	229	GT04-112×YC90-33	2
Y70	YT94-128×ROC22	3	1124	GT02-761×YF90-95	2
399	Co1001×GT10-2018	3	381	GT05-wm48×GT07-229	2
981	SWS09-001×CP92-1641	3	670	CP00-1630×GT06-1184	2
564	GT02-761×YC07-71	3	975	GT05-ym3×LC03-1137	2
989	C1-2003×YZ95-128	3	142	CP07-1618×YG22	2
283	GT06-3283×LT07-95	3	643	GT02-901×GT06-178	2
Y12	ROC28×YT00-236	3	371	CP07-1618×LC03-1137	2
Y44	YT00-318×YT93-159	3	289	NongL8×GT09-1009	2
Y50	YT01-71×DZ93-88	3	370	CP07-1618×FN39	2
506	GT06-1264×YT96-833	3	430	YZ99-596×GT10-2018	1
1252	GT05-3661×CP09-4256	3	875	FR93-865×PR83-1248	1
Y86	ZZ33×GT92-66	3			
1245	GT01-25×CP09-4707	3			
327	GT04-1023×FN39	3			

In this study, we identified the relationship between the lodging level and brix and stem diameter in sugarcane. When lodging occurred, the brix was down. Mo (1979) reported that the brix declined after lodging in sugarcane, which is in accordance to the results of this study. In addition, for the first time, this research used the data of the ratio of basal and middle stem diameter. The higher the ratio was, the higher lodging resistance index of sugarcane was. Apparently, they were positively correlated. When the ratio was lower than one, the lodging resistance index decreased and the degree of lodging was significantly higher, caused by the heavy top and light base (Peng, 1988; Feng et al., 2006). In the breeding process of sugarcane or other stalk crops, the breeders preferred to choose the ideal plant type – “tower type” (Liu, 2017). This structure was stable and could minimize losses even in bad weather such as strong wind (Johnson et al., 1998). Especially for the large leafed sugarcane, it is necessary to maintain the stability by selecting the “tower” structure. Therefore, the introduction of the ratio of basal and mid stem diameters would help the breeders to judge sugarcane lodging resistance more comprehensively.

There had been many studies on breeding and selecting resistance traits such as drought resistance, cold resistance and smut resistance by sugarcane germplasm resources (Agboire et al., 2000; Cai et al., 2008; Pan et al., 2006; Zhou et al., 2012). An excellent sugarcane variety was always selected from hundreds of sugarcane combinations (Yang et al., 2011). High yield, high sucrose content, strong ratoon ability and multi-resistance were the breeding targets (Mbuma et al., 2018; Huang et al., 2016; Zhou et al., 2017). However, the most prominent problem encountered in conventional breeding was the narrow genetic basis and insufficient parental innovation, which greatly affects the selection of new breakthrough sugarcane varieties. It is even more difficult to obtain new sugarcane varieties with specific characteristics (Duan et al., 2017; Ramburan et al., 2010). For lodging resistant breeding, it was necessary to have lodging resistant sugarcane germplasm resources (Sengwayo et al., 2018). In this research, based on the lodging resistance index, 30 combinations were classified into three levels, sixteen in level 3, thirteen in level 2, and two in level 1. In the combinations of lodging resistance, GT and YT parents were accounted for 56% and 44% respectively; In the combination of middle lodging, CP parents were accounted for 30%, indicating that the sugarcane varieties (clones) selected and planted in the local climate zone could better adapt to the cultivation environment. In China, the breeders consider more about the effect of lodging on commercial sugarcane production, so they prefer to select the clones with lodging resistance (Yang et al., 2019; Wu et al., 2019). Because of the complete sugarcane mechanization in the USA, the sugarcane breeders mainly considered yield and sugar, and the lodging resistance of sugarcane might be not the main target (Zhou and Li, 2012). Continuous evaluation of the lodging resistance of germplasm resources, statistical analysis of excellent combinations and excellent parents would be helpful to breed lodging resistant sugarcane varieties.

The instrument for measuring the resistance force, DIK7401, did not produce good results in sugarcane. Considering the limit of measurement range of the instrument, and that sugarcane is relatively high and the stem has strong tenacity, the thrust required should be much higher than that for rice (Xiong et al., 2018) and wheat (He, 2018). In the next step, we will consider to use a broader ranged resistance force tester for the study, and NKK-4005 computer-controlled universal testing machine may be used to measure the mechanical indexes of different lodging forms of sugarcane, such as leaf, skin endurance and stem bending resistance (Yang et al., 2016).

Conclusion

In this study, lodging grades and lodging resistance index were established for sugarcane. According to the lodging degree, sugarcane lodging could be divided into three grades, that is, grade 1 (complete lodging), grade 2 (half lodging) and grade 3 (erect). The established lodging resistance index could be used to evaluate the lodging resistance of sugarcane quickly. The relationship between lodging and brix and stem diameter was confirmed. The brix in cane juice decreased when lodging occurred. The ratio of basal and mid stem diameters was found highly significantly correlated with the lodging resistance in sugarcane. When the ratio was less than one, the lodging resistance index of sugarcane was low and the lodging degree was obviously heavy. With the lodging resistance index, the thirty combinations used in this study were divided into three categories, sixteen in grade 3, thirteen in grade 2, and two in grade 1.

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REFERENCES

- [1] Agboire, S., Wada, A. C., Ishaq, M. N. (2000): Evaluation and characterisation of sugar cane germplasm accessions for their breeding values in Nigeria. – *Journal of Food Technology in Africa* 7(1): 33-35.
- [2] Cai, Q., Aitken, K. S., Deng, H. H., Chen, X. W., McIntyre, C. L. (2008): Verification of the introgression of *erianthus arundinaceus* germplasm into sugarcane using molecular markers. – *Plant Breeding* 124(4): 322-328.
- [3] Duan, W. X., Huang, Y. X., Zhou, S., Zhang, B. Q., Luo, T., Yang, C. F., Gao, Y. J., Zhang, G. M. (2017): Transmission of parental chromosomes in F₁, BC₁ and BC₂ progeny between *Saccharum spp. hybrid* and *Narenga porphyrocoma* (Hance) Bor. – *Chinese Journal of Tropical Crops* 38(12): 2201-2005.
- [4] Feng, Y. X. (2006): Planting good autumn sugarcane to develop sugar industry. – *Guangxi Sugar Industry* 4: 43-45.
- [5] Hao, W. L., Liu, H. X., Zhu, L., Meng, Q. H. (2008): General provisions for methods for determining conditions of agricultural machinery test. – *PRC National Standard* 65: 2.
- [6] He, H. H. (2018): Physical and chemical characteristics related to lodging resistance in wheat. – Wuhan: M. S. Thesis of Huazhong Agricultural University 35: 1023.
- [7] Huang, J. Y., Li, X., Tan, F., Tang, S. Y., Wang, L. W., Huang, H. R. (2016): Breeding and characterization of a new sugarcane variety Guitang 49. – *Subtropical Agriculture Research* 12(2): 73-78.
- [8] Johnson, D. E., Dingkuhn, M., Jones, M. P., Mahamane, M. C. (1998): The influence of rice plant type on the effect of weed competition on *Oryza sativa* and *Oryza glaberrima*. – *Weed Research* 38(3): 207-216.
- [9] Kamran, M., Ahmad, I., Wang, H., Wu, X., Jing, X., Liu, T. (2018): Mepiquat chloride application increases lodging resistance of maize by enhancing stem physical strength and lignin biosynthesis. – *Field Crops Research* 224: 148-159.
- [10] Kimbeng, C. A., Mcrae, T. A., Stringer, J. K., Hogarth, D. M. (2000): Gains from family and visual selection in sugarcane, particularly for heavily lodged crops in the Burdekin region. – *Conference of the Australian Society of Sugar Cane Technologists* 37: 68-72.

- [11] Li, C. S., Huo, X. J., Wei, S. L., Wei, D., Wei, H. F., Huang, S. M. (2012): Evaluation of 5 banana varieties for resistance to Fusarium wilt. – Journal Of Southern Agriculture 43(4): 449-453.
- [12] Li, X., Li, Y. J., Liang, Q., Lin, S. H., Huang, H. R., Huang, Q. Y. (2018): Adaptability of sugarcane clone in Nanning ecological region. – Guangxi Sugar Industry 22: 129-130.
- [13] Li, Y. R. (2010): Modern Sugarcane Science. – China Agriculture Press, Beijing, pp. 121-122.
- [14] Li, Y. R., Mao, C. C., Tang, Q. Z. (2010): Reasons and countermeasures for sugar yield decrease in Asian countries in 2008-2009. – Guangxi Agricultural Science 41(1): 80-84.
- [15] Liu, F. X. (2017): Discussion on the reasonable combination of maize plant type and dense planting. – Agricultural Service 22: 103.
- [16] Liu, G. L., Fan, H. W. (2011): A better active design for optimizing grinding parameters of aviation spiral bevel gears. – Journal of Northwest Polytechnical University 32(3): 92-97.
- [17] Mbuma, N. W., Zhou, M., Merwe, R. V. D. (2018): Evaluating parents for cane yield in sugarcane breeding using best linear unbiased prediction analysis of progeny data derived from family plots. – South African Journal of Plant and Soil 13: 1-8.
- [18] Mo, J. Y. (1979): Preliminary analysis of adverse physiological effects of sugarcane lodging – Sugar Industry (12): 22-24.
- [19] Nakajima, T., Yoshida, M., Tomimura, K. (2008): Effect of lodging on the level of mycotoxins in wheat, barley, and rice infected with the fusarium graminearum species complex. – Journal of General Plant Pathology 74(4): 289-295.
- [20] Pan, S. M., Chen, Y. Q., Wu, J. S., Zhang, M. Q. (2006): Screening and evaluation of the drought resistant germplasm in sugarcane. – Journal of Jiangxi Agricultural University 28(6): 838-843.
- [21] Peng, S. G. (1988): Review of 30 years of sexual crossbreeding of sugarcane in Guangxi. – Southwest Agricultural Journal (3): 15-22.
- [22] Piñera-Chavez, F. J., Berry, P. M., Foulkes, M. J., Molero, G., Reynolds, M. P. (2016): Avoiding lodging in irrigated spring wheat. ii. genetic variation of stem and root structural properties. – Field Crops Research 196: 64-74.
- [23] Ramburan, S., Paraskevopoulos, A., Saville, G., Jones, M. (2010): A decision support system for sugarcane variety selection in south africa based on genotype-by-environment analyses. – Experimental Agriculture 46(2): 243.
- [24] Sengwayo, S., Zhou, M., Labuschagne, M. (2018): Trends in broad-sense heritability and predicted selection gains for the coastal short cycle breeding sugarcane programmes in South Africa. – South African Journal of Plant & Soil 35(2): 89-99.
- [25] Singh, G., Chapman, S. C., Jackson, P. A., Lawn, R. J., Hogarth, D. M. (1999): Yield accumulation in sugarcane under wet tropical conditions - effect of lodging and crop age. – Proceedings of the Australian Society of Sugar Cane Technologists 21: 241-245.
- [26] Singh, G., Chapman, S. C., Jackson, P. A., Lawn, R. J. (2002): Lodging reduces sucrose accumulation of sugarcane in the wet and dry tropics. – Australian Journal of Agricultural Research 53(11): 1183-1195.
- [27] Stamp, P., Kiel, C. (2010): Root morphology of maize and its relationship to root lodging. – Journal of Agronomy & Crop Science 168(2): 113-118.
- [28] Wang, X. D., Wang, M. Q., Wang, H. X. (2014): Analysis on the relationship between yield components and yield of rice germplasm in cold region. – Heilongjiang Agricultural Sciences 6(3): 153-172.
- [29] Wang, Y., Wei, Z. W., Shao, P., Tian, X. H., Wang, X. L., Ma, G. H. (2015): Research status on relationship between culm characteristics and lodging resistance of rice. – Hubei Agricultural Sciences 34: 2054-2057.
- [30] Wu, J. Y., Huang, J. J., Ling, Q. P., Chen, Y. S., Zeng, Q. Y., Yang, Z. D., Qi, Y. W., Li, Q. W. (2019): Preliminary identification and evaluation of 12 strains of HoCP series in sugarcane germplasm resources. – Journal of Tropical and Subtropical Botany 1: 53-59.

- [31] Xie, Z. S., Zhang, X., Chen, Y. Y., Luo, S. R., Wei, S. Y. (2009): Assessment of banana germplasm for resistance to fusarium wilt. – Chinese Journal of Tropical Crops 30(3): 362-364.
- [32] Xiong, W., Fengying, X. U., Wang, X. (2018): Effect of different nitrogen application rate on rice stem characteristics. – Agricultural Biotechnology 40(2): 56-62.
- [33] Yang, R. Z., Li, Y. R., Wang, W. Z., Zhu, Q. Z., Zhou, H., Tang, S. Y. (2011): Evaluation of cold tolerance of sugarcane under drought frost condition. – Agricultural Science & Technology 24: 1303-1307.
- [34] Yang, R. Z., Zhou, H., Lei, J. C., Duan, W. X., Li, Y. R., Tang, S. Y., Li, W. J., Yang, C. F., Gao, Y. J., Zhou, S. (2019): The harvest index of different sugarcane varieties. – Sugar Crops of China 41(1): 8-12.
- [35] Yang, W., Mo, X. M., Yang, J., Yuan, F. W., Huang, S. C. (2016): Experimental study on the basic parameters of sugarcane on easy lodging period. – Journal of Agricultural Mechanization Research 12: 143-148.
- [36] Zhang, X. C., Hu, Y., Yang, Z. J. (2010): Cutting movement analysis of spiral bevel gear based on the tooth generating line. – Journal of Beijing University of Technology 28(11): 63-67.
- [37] Zhou, H., Li, Y. R. (2012): Analysis on sugarcane varieties bred in the United States of America. – Journal of Southern Agriculture 43(5): 570-577.
- [38] Zhou, H., Lei, J. C., Gui, Y. Y., Xian, W., Liang, Q., Yang, R. Z., Li, Y. R. (2012): Evaluation on cold tolerance of sugarcane varieties under field conditions. – Journal of Plant Genetic Resources 13(6): 968-973.
- [39] Zhou, Z. F., Deng, Y. C., Wang, L. W., Xian, W., Tan, F., Huang, H. R. (2017): Selection and species evaluation of sugarcane variety Guitang 47. – China Seed 2: 62-64.