Journal of Global Biosciences
ISSN 2320-1355
Volume 4, Number 6, 2015, pp. 2459-2467
Website: www.mutagens.co.in
E-mail: submit@mutagens.co.in
researchsubmission@hotmail.com

Research Paper

EVALUATION OF COLD TOLERANCE AND PHOTOSYNTHETIC CHARACTERISTICS IN DIFFERENT SUGARCANE GENOTYPES

Shi-Yun Tang[1, 2], Yang-Rui Li[1, 2] and Li-Tao Yang[1, 2]

[1] Agricultural College, Guangxi University/ State Key Laboratory of Conservation and Utilization of Subtropical Agro-Bioresources, Nanning 530005, China;
[2] Guangxi Key Laboratory of Sugarcane Genetic Improvement, Sugarcane Research Center, Chinese Academy of Agricultural Sciences, Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, Nanning 530007, China.

Abstract

In order to evaluate the cold tolerance and photosynthetic characteristics in different sugarcane genotypes, and understand the correlations between changes of photosynthetic characteristics and cold tolerance, 7 newly bred sugarcane lines from Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, and 2 commercial main cultivars were used as plant materials in present study. The plants were grown at 4°C chamber for 0, 7, 15, 25, 31 and 38 days as low temperature treatment, while the control was at room temperature (about 25°C). Chilling injury index, chlorophyll content and photosynthetic parameters under low temperature stress were determined. The results showed that chilling injury index increased with the rise of low temperature treatment days, while changes of chilling injury in different sugarcane genotypes were different. Chlorophyll content decreased as the days of low temperature treatment increased. Under cold stress, net photosynthetic rate (Pn) and stomatal conductance (Gs) decreased sharply; Pn and Gs showed significant differences between control and low-temperature treatment. Maximum efficiency of light energy conversion (Fv/Fm), PSII actual quantum efficiency (ΦPS□), reaction center of excitation energy capture (Fv′/Fm′), photochemical quenching coefficient (qP) and electron transfer rate (ETR) significantly decreased under cold stress, but initial fluorescence (Fo), Steady state fluorescence (Fs) and non photochemical quenching coefficient (qNP) increased. Different genotypes showed differences in photosynthetic capacity and chlorophyll fluorescence. Both chlorophyll content and photosynthetic parameters had positive correlations with chilling injury indexes, especially Fv/Fm, Fv′/Fm′ and ΦPS□showed highly positive correlation coefficients with the chilling injury indexes, so Fv/Fm, Fv′/Fm′, ΦPS□ could be used as the indexes of cold tolerance in sugarcane.

Key words: *Sugarcane, Cold Tolerance, Photosynthetic Characteristics, Chlorophyll Fluorescence, Genotype*.

INTRODUCTION

It is well known that sugarcane is one of the sugar crops grown in tropical and subtropical regions, and its growth and development need appropriate temperature. Guangxi is the largest sugarcane producer in China, and its sugar output made up over 70 percent of China's sugar production [1]. Cold temperature affects the growth and development of sugarcane and will lead to considerable decrease in cane yield and sugar quality, especially cold temperature injury, which resulted in a great deal of economic losses in Guangxi in recent years [2] [3] [4] [5] [6]. It has been proved that breeding cold tolerant sugarcane varieties is one of most effective measures to reduce losses caused by cold temperature. Especially, ROC22, the main cultivar in Guangxi, is sensitive to low temperature stress, so it is necessary to breed new cold resistant cultivars.

Chlorophyll fluorescence technique has been applied for years to study the relationship between photosynthesis and environment, which could be used to investigate the efficiency of light energy absorption, status of excitation energy transfer and photochemistry reaction [7] [8] [9]. Chlorophyll fluorescence analysis has been developed as one of the practical techniques; it is fast, sensitive, simple, accurate and scatheless in photosynthesis research, and shows broad prospects for identification of cold tolerance. It was reported that cold tolerance of rice [10] [11], maize [12], wheat [13], banana [14], pepper [15], cauliflower [16], cucumber [17] [18], sugarcane [19], eggplant [20] and tomato [21] could be identified by chlorophyll fluorescence technique.

This study was conducted to investigate the chilling injury index and photosynthetic parameters of different varieties (lines) under cold temperature stress, and reveal the relationship between cold tolerance and change of photosynthetic characteristic, to provide references for screening cold resistant cultivar in sugarcane breeding program.

MATERIALS AND METHODS

Plant materials

Seven newly bred sugarcane lines, namely, GT08-58, GT08-162, GT08-297, GT08-460, GT08-777, GT08-1092, GT08-1180 from Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, and 2 commercial main cultivars, ROC16 and ROC22, were used as plant materials in the present study.

Experimental design

Both 7 sugarcane lines and 2 cultivars used as experiment materials were planted in plastic pots with 25 cm in diameter and 30 cm in depth; each genotype was planted in 6 pots, and 6 single-bud setts were planted in each pot, therefore, 54 pots of seedlings was planted for all treatments. The 9 genotypes were arranged in a completely randomized design with 3 replications, and each replication contained 18 pots. The 116 days old seedlings with about 12 leaves were placed in an artificial climate chamber at 4 ^{o}C and subjected to cold treatment; during cold treatment, artificial lights were supplied in the chamber from 8:00 am to 18:00 pm, and the cold treatment was ended after 38 d of treatment.

Measuring method

Chilling injury indexes were measured at 0, 7, 15, 25, and 38 days after cold treatment. According to the damage degree of leaf 0 of the seedlings, chilling injury indexes were divided into 5 grades: The criterion of grade 0 was for those that leaf tip and edge were not curled and leaf was fresh. The criterion of grade 1 was for those that leaf tip was curled but leaf edge was not curled. The criterion of grade 2 was for those that leaf tip and leaf edge were curled. The criterion of grade 3 was for those that leaf tip and edge were curled and leaf tip became withered. The criterion of grade 4 was for those that leaf tip and edge were curled and leaf became withered. The criterion of grade 5 was for those that all leaf became withered and the plant was dying. Chilling injury indexes=$\sum$(plant number×grade number)/total number.

The sugarcane seedlings were removed out from the chamber and revived for 3 hours at normal temperature, and 3 leaves +2 were taken as samples in each treatment, chlorophyll content was determined with SPAD502, and photosynthesis parameters were measured with

LI-6400 portable photosynthesis system after 30 minutes of dark adaptation, and chlorophyll fluorescence parameters were measured with FMS-2 chlorophyll fluorometer.

Statistical analysis

Analyses of variance (ANOVA) were done with the General Linear Model Procedure of DPS software, and the correlation coefficients between photosynthetic parameters and chilling injury indexes were analyzed.

RESULTS AND ANALYSES

Influence of cold treatment on chilling injury indexes

With the prolongation of low temperature treatment, chilling injury indexes of all the lines (varieties) were increased, but different lines (varieties) had different increasing degree (Table 1). There was no significant difference in chilling injury indexes in different lines at 7 d of low temperature treatment, and only mild cold damage symptoms were appeared at 15 d of low temperature treatment, but at 25 d of low temperature treatment, moderate cold damage symptoms were observed and chilling injury indexes were significantly different in different lines (varieties). At 31 d of low temperature treatment, severe cold damage symptoms appeared, but the difference of chilling injury indexes was not significant in different lines (varieties). At 38 d of low temperature treatment, all plants were dying.

Table 1 The chilling injury index of 9 sugarcane genotypes under low temperature stress

Treatment Time (d)	Sugarcane genotype									Mean	Standard deviation
	GT08-158	GT08-162	GT08-297	GT08-460	GT08-777	GT08-1092	GT08-1180	ROC22	ROC16		
0	0	0	0	0	0	0	0	0	0	0	0
7	0	0.5	0	0.5	0.5	0	0	0.5	0	0.2	0.2
15	0.5	1	0	1	1	0.5	0	1	0.5	0.6	0.4
25	1.5	3	0.5	3	3	1.5	0.5	3	1.5	1.9	1.0
31	3	3	3.5	3	3.5	4	3.3	3.5	3	3.3	0.3
38	4.3	5	5	4	4.8	4.5	4.8	4.7	4.5	4.6	0.3

As far as sugarcane genotypes was concerned, GT08-162, GT08-777 and ROC22 suffered from mild cold damage at 7 d of low temperature treatment, which chilling injury indexes were higher at 38 d of low temperature treatment, therefore, GT08-162, GT08-777 and ROC22 were sensitive to low temperature and regarded as cold sensitive varieties. At 15 d of low temperature treatment, GT08-158 and GT08-1092 showed mild cold damage symptom, which chilling injury indexes were lower at 38 d of low temperature treatment, so GT08-158 and GT08-1092 were regarded as cold resistant varieties. GT08-297 and GT08-1180 suffered from mild cold damage at 25 d of low temperature treatment, but their chilling injury indexes were higher at 38 d of low temperature treatment, so GT08-297 and GT08-1180 could only endure cold stress for short time. GT08-460 and ROC16 showed mild symptoms at 7 d of low temperature treatment, but their chilling injury indexes were lower at 38 d of low temperature treatment, so 460 and ROC16 could endure cold stress for a longer time (Table 1).

Influence of cold stress treatment on chlorophyll content and photosynthetic characteristics

With the increasing of low temperature treatment duration, the chlorophyll content was decreased remarkably, and there were significant difference between chlorophyll content at 25 d of treatment and chlorophyll content at 0 d of treatment, but change trend of chlorophyll content differed in different sugarcane genotypes, from 0 to 25 d, GT08-158 had the maximal decreasing range of SPAD, and the order for other genotypes showed GT08-460, ROC16, GT08-162, GT08-297, GT08-1180, GT08-1092, ROC22, GT08-777.

Table 2 Changes of chlorophyll content of 9 sugarcane genotypes under low temperature stress

Sugarcane genotype	SPAD				
	0 d	7 d	15 d	25 d	Decrease rate (%)
GT08-158	40.8a	40.7a	31.1b	22.0c	46.2
GT08-162	34.1a	29.8ab	26.9b	26.1b	23.6
GT08-297	42.2a	39.9a	37.3ab	32.8b	22.2
GT08-460	38.5ab	40.2a	34.1b	24.5c	36.3
GT08-777	43.7a	41.7ab	40.3ab	35.8b	18.3
GT08-1092	41.9a	39.2ab	36.2ab	33.5b	19.9
GT08-1180	45.1a	43.8a	40.1ab	35.9b	20.4
ROC22	42.0a	36.2ab	32.6b	34.0b	19.2
ROC16	41.0a	40.6a	36.7a	27.0b	34.1

Notes: The data with different letters are significantly different at $P<0.05$.

Net photosynthetic rate (Pn) was decreased markedly under low temperature stress, and there were significant differences between Pn at 0 d of treatment and Pn at 7 d of treatment. The decrease from 0 to 25 d was very large, and Pn at 25 d of low temperature treatment was almost zero. For genotypes, GT08-162 had the maximal decrease of Pn and ROC16 had the minimal decrease of Pn.

Under low temperature stress, the decreasing trend of stomatal conductance (Gs) was the same as Pn, and Gs had significant and positive correlation with Pn, so the decrease of Gs should be an important reason for the decrease of Pn. the decrease of Gs at 25 d of low temperature treatment was above 90% of that at 0 day of temperature treatment, Gs at 7, 15 and 25 d of low temperature treatment showed significant difference from Gs at 0 d of low temperature treatment (Tables 2 and 3).

Table 3 Changes of photosynthetic rate and stomatal conductance of 9 sugarcane genotypes under low temperature stress

Sugarcane genotype	Pn					Gs				
	0 d ($\mu mol.m^{-2}.s^{-1}$)	7 d ($\mu mol.m^{-2}.s^{-1}$)	15 d ($\mu mol.m^{-2}.s^{-1}$)	25 d ($\mu mol.m^{-2}.s^{-1}$)	Increase rate (%)	0 d ($mmol.m^{-2}.s^{-1}$)	7 d ($mmol.m^{-2}.s^{-1}$)	15 d ($mmol.m^{-2}.s^{-1}$)	25 d ($mmol.m^{-2}.s^{-1}$)	Decrease rate (%)
GT08-158	14.7a	2.3b	1.4b	2.6b	82.4	0	7	15	25	95.3
GT08-162	24.3a	3.0b	1.5b	0.9b	96.4	0.122a	0.006b	0.005b	0.006b	94.9
GT08-297	24.1a	4.6b	3.7b	1.7b	93.2	0.283a	0.020b	0.010b	0.014b	96.1
GT08-460	23.2a	3.5b	2.9b	2.3b	90.2	0.324a	0.027b	0.030b	0.013b	95.0
GT08-777	18.9a	4.3b	1.8b	3.2b	83.1	0.247a	0.008b	0.018b	0.012b	97.8
GT08-1092	21.6a	11.0b	3.0c	2.1c	90.1	0.186a	0.042b	0.004b	0.004b	94.8
GT08-1180	16.1a	2.5b	2.7b	2.2b	86.3	0.211a	0.079b	0.020c	0.011c	93.3
ROC22	20.5a	2.0b	1.0b	2.8b	86.2	0.161a	0.005b	0.005b	0.011b	92.9
ROC16	21.9a	6.2b	4.3b	4.7b	78.7	0.189a	0.013b	0.001b	0.013b	94.4

Notes: The data with different letters are significantly different at $P<0.05$.

Table 4 Changes of Fo and Fv/Fm of 9 sugarcane genotypes under low temperature stress

Sugarcane genotype	Fo					Fv/Fm				
	0 d	7 d	15 d	25 d	Increase rate (%)	0 d	7 d	15 d	25 d	Decrease rate (%)
GT08-158	121c	145bc	168b	296a	144.0	0.824a	0.746b	0.613c	0.511d	37.9
GT08-162	106c	142b	161b	346a	225.7	0.818a	0.695b	0.442c	0.338d	58.6
GT08-297	110b	126b	122b	251a	127.9	0.818a	0.774a	0.679b	0.492c	39.9
GT08-460	71c	103b	140b	197a	177.5	0.831a	0.789a	0.636b	0.521c	37.3
GT08-777	101c	139b	161b	247a	144.6	0.813a	0.774a	0.669b	0.463c	43.1
GT08-1092	122c	142bc	168b	213a	74.6	0.814a	0.765a	0.630b	0.559c	31.4
GT08-1180	114c	124c	200b	253a	121.0	0.816a	0.751b	0.560c	0.513c	37.1
ROC22	77c	147b	175b	273a	254.1	0.833a	0.775b	0.544c	0.500c	40.0
ROC16	105c	128c	162b	211a	100.6	0.820a	0.782a	0.615b	0.559c	31.9

Notes: The data with different letters are significantly different at P<0.05.

Influence of low temperature on chlorophyll fluorescence parameters

When the PS□ reaction center complex was completely open, the fluorescence value was named initial fluorescence (Fo). Maximal photochemical quantum yield of PSII (Fv/Fm) was used to determine the conversation efficiency of primary light energy. It was reported that under normal conditions the change of Fv/Fm was little, but under stress conditions Fv/Fm would be decreased markedly [22]. From Table 4, it was observed that Fo increased under low temperature, but Fv/Fm decreased, and both Fo and Fv/Fm had significant difference between 25 d of treatment and 0 d of treatment. For genotypes, ROC22 had the largest increase of Fo and the large decrease of Fv/Fm, and GT08-1092 had the lowest increase of Fo and the lowest decrease of Fv/Fm.

From Tables 5 and 6, it was found that actual quantum efficiency (ΦPS□) decreased as the low temperature treatment days increased, and it showed significant difference between 0 d and 25 d treatments. For genotypes, GT08-162 had the highest decrease and GT08-1092 had the lowest decrease of ΦPS□.

Table 5 Changes of ΦPSⅡ and Fv′/Fm′ of 9 sugarcane genotypes under low temperature stress

Sugarcane genotype	ΦPSⅡ					Fv′/Fm′				
	0 d	7 d	15 d	25 d	Decrease rate	0 d	7d	15 d	25 d	Decrease rate
GT08-158	0.741a	0.657b	0.502c	0.427d	42.4	0.782a	0.695b	0.579c	0.494d	36.8
GT08-162	0.716a	0.534b	0.313c	0.222d	69.0	0.766a	0.608b	0.399c	0.277d	63.8
GT08-297	0.733a	0.622b	0.596b	0.408c	44.3	0.786a	0.677b	0.649b	0.461c	41.3
GT08-460	0.780a	0.708a	0.542b	0.438c	43.9	0.817a	0.751a	0.592b	0.506c	38.1
GT08-777	0.731a	0.664a	0.574b	0.410c	43.9	0.774a	0.712a	0.622b	0.469c	39.4
GT08-1092	0.729a	0.675a	0.559b	0.467c	35.8	0.772a	0.716a	0.599b	0.524c	32.1
GT08-1180	0.722a	0.633b	0.436c	0.413c	42.8	0.775a	0.691b	0.506c	0.469c	39.5
ROC22	0.746a	0.676a	0.461b	0.424b	43.3	0.787a	0.722a	0.517b	0.476b	39.5
ROC16	0.755a	0.645b	0.504c	0.476c	36.9	0.788a	0.691b	0.568c	0.520c	34.0

Notes: The data with different letters are significantly different at P<0.05.

Table 6 Changes of Fs and ETR of 9 sugarcane genotypes under low temperature stress

Sugarcane genotype	Fs					ETR				
	0 d	7 d	15 d	25 d	Increase rate	0 d	7 d	15 d	25 d	Decrease rate
GT08-158	150b	167b	183b	293a	94.9	4.485ab	3.968b	4.512a	3.430c	23.5
GT08-162	140c	183b	175bc	372a	165.1	6.699a	2.880c	3.926b	2.450c	63.4
GT08-297	140b	160b	134b	241a	72.7	6.854a	5.287b	3.459c	3.608c	47.4
GT08-460	86c	120bc	153ab	188a	118.9	5.235a	4.611b	5.181a	3.104c	40.7
GT08-777	127b	165ab	180a	200a	56.8	6.698a	4.218c	4.745b	3.741c	44.1
GT08-1092	159b	163b	178ab	213a	34.0	6.417a	2.731c	4.513b	4.560b	28.9
GT08-1180	149bc	139c	186b	240a	60.6	7.009a	2.751c	4.406b	4.342b	38.1
ROC22	109c	161b	179b	264a	141.6	7.463a	4.266b	3.137c	3.631c	51.3
ROC16	124c	145bc	174b	216a	74.2	5.541a	3.433c	4.045b	4.357b	21.4

Notes: The data with different letters are significantly different at P<0.05.

The maximal photochemical efficiency of PSII in light adaptation status (Fv′/Fm′), steady state fluorescence (Fs) and electron transport rate of PS□(ETR) had the same change trend, which showed decreased as the treatment days increased, and Fv′/Fm′, Fs and ETR had significant difference between 25 d and 0 d treatments. For genotypes, GT08-162 had the highest decrease rate of Fv′/Fm′, Fs and ETR while GT08-1092 had the lowest decrease rate of Fv′/Fm′ and Fs. ROC16 had the lowest decrease rate of ETR.

Photochemical quenching coefficient (qP) is used to measure the share of light energy as transported photochemical electron, and it also reflects the open degree of PSII reaction center. Non-photochemical quenching (qNP) was used to measure the proportion of light energy which was dissipated by heat [7] [8].

Data in Table 7 showed that qP decreased under low temperature stress, and it had significant difference between 25 and 0 day treatments. For genotype, GT08-162 showed the highest and ROC16 the lowest qP.

Table 7 Changes of qP, qNP and ETR of 9 sugarcane genotypes under low temperature stress

Genotypes	qP					qNP				
	0 d	7 d	15 d	25 d	Decrease rate	0 d	7 d	15 d	25 d	Increase rate
GT08-158	0.948a	0.946a	0.867b	0.865b	8.8	0.191a	0.192a	0.235a	0.267a	39.8
GT08-162	0.935a	0.874b	0.785c	0.799c	14.5	0.185a	0.231a	0.277a	0.251a	35.5
GT08-297	0.933a	0.919ab	0.918ab	0.884b	5.2	0.163c	0.355ab	0.185bc	0.316a	94.6
GT08-460	0.955a	0.942a	0.916a	0.866b	9.4	0.108b	0.193ab	0.219ab	0.310a	187.0
GT08-777	0.945a	0.931a	0.922a	0.864b	8.6	0.133c	0.254b	0.195bc	0.392a	193.9
GT08-1092	0.945a	0.942a	0.933ab	0.891b	5.7	0.140b	0.215ab	0.167ab	0.282a	102.0
GT08-1180	0.933a	0.915ab	0.861bc	0.879c	5.7	0.170b	0.300ab	0.416a	0.359a	111.3
ROC22	0.949a	0.935ab	0.892b	0.889b	6.3	0.170a	0.280a	0.229a	0.277a	62.7
ROC16	0.958a	0.931ab	0.885ab	0.914b	4.6	0.170b	0.373a	0.257ab	0.222b	30.5

Notes: The data with different letters are significantly different at P<0.05.

It was showed that qNP increased with the duration of cold stress, but the change trend of qNP was different with different genotypes, GT08-777 showed the highest decrease rate and ROC16 showed the lowest decrease rate.

Analysis of correlation coefficients between chilling injury index and photosynthetic parameters

The data in Table 8 showed that SPAD, Pn, Gs and chlorophyll fluorescence parameters had significant correlation with chilling injury index. Fv/Fm, Fv′/Fm′ and ΦPS□had above 0.800 correlation coefficients with chilling injury index, so Fv/Fm, Fv′/Fm′, ΦPS Ⅱ could be used as the indexes for cold tolerance of sugarcane genotypes.

DISCUSSION

The effects of low temperature on sugarcane was complicated, and both morphological and physiological characteristics were influenced under cold stress. Low temperature damaged the chloroplast ultrastructure, retarded the chlorophyll biosynthesis, and degraded the photosynthetic pigment, which resulted in a decreased SPAD. In the present experiment, SPAD had significant and negative correlation with chilling injury index, and the result was the same as the result reported by Li et al. [11].

Table 8 correlation coefficients between photosynthetic traits and chilling injury index

	SPAD	Pn	Gs	Fo	Fv/Fm	Fs	Fv′/Fm′	ΦPSⅡ	qP	qNP	ETR
Pn	0.479										
Gs	0.437	0.983									
Fo	-0.667	-0.601	-0.567								
Fv/Fm	0.757	0.689	0.646	-0.893							
Fs	-0.661	-0.539	-0.498	0.965	-0.819						
Fv′/Fm′	0.748	0.728	0.684	-0.889	0.989	-0.836					
ΦPSⅡ	0.755	0.730	0.684	-0.873	0.986	-0.821	0.998				
qP	0.721	0.589	0.530	-0.720	0.878	-0.700	0.898	0.920			
qNP	-0.254	-0.619	-0.614	0.534	-0.536	0.416	-0.585	-0.596	-0.545		
ETR	0.505	0.763	0.758	-0.558	0.588	-0.512	0.617	0.614	0.520	-0.502	
I	-0.700	-0.655	-0.619	0.792	-0.872	0.703	-0.846	-0.833	-0.649	0.419	-0.471

Notes: $P<0.05(r=0.3291)$, $P<0.01(r=0.4238)$

Photosynthesis was the approach of organic material synthesis and energy gain in plant, but photosynthesis was markedly decreased by low temperature stress [10] [12] [14] [17] [20]. In this study, Pn was significantly decreased under low temperature stress, and Pn had a significant correlation with chilling injury index.

Chlorophyll fluorescence analysis represented the intrinsic probe, which was based on chlorophyll in vivo, and was closely related to photosynthesis process. Any influence of low temperature in photosynthesis could be showed by chlorophyll fluorescence analysis, so chlorophyll fluorescence parameters could be used to evaluate the effect of cold stress [19] [23] [24], and help to know where and how it was damage in photosynthetic structure [25]. Under low temperature stress, PSⅡ reaction center would be inactivated with the increase of Fo, and the potential activity of PSⅡ and conversation efficiency of primary light energy would be weakened as ETR, Fv/Fo and Fv/Fm decrease [26].

As one of the sensitive indexes for cold tolerance, Fv/Fm had been used to determine cold tolerance in many plants, such as maize [27], Douglas fir (*Pseudotsuga menziesii*) [28], asparagus bean [29], rice [11]. In many studies, it was reported that the suppression degree of Fv/Fm, Fv/Fo, ΦPSII, Rfd, qP, qN and Yield had significant and positive correlation with the environmental stress degree, but as indexes for stress tolerance, Fv/Fm, Fv/Fo, ΦPSII, Rfd, qP, qN and Yield had different effect in different plant [8]. Li et al. [16] reported that Fv/Fm had significant and positive correlation with cold tolerance in cauliflower. Xie et al. [15] reported that ΦPSⅡ and Fv ′ had significant and negative correlation with cold tolerance in capsicum. In the present study, with the low temperature treatment prolonging, Fo was increased, and FV/FM, ΦPSⅡand Fv′/Fm′ was decreased. Fo, FV/FM, ΦPSⅡ and Fv′/Fm′ had significant correlation with chilling injury index, so Fo, FV/FM, ΦPSⅡ and Fv′/Fm′ could be used as the cold tolerance indexes in sugarcane.

Zhang et al. [19] studied the effect of low temperature stress in sugarcane seedlings by chlorophyll fluorescence techniques, and the result showed that Fv/Fm, Fv/Fo, DCPIP, Yield, Rfd, qP and qN were decreased, the primary light energy conversion of PSⅡand the potential photosynthetic activity were inhibited, and the inhibition degree of cold sensitive varieties significantly higher than that of cold resistant varieties.

In the present study, FV/FM decreased as the days of low temperature increased, and FV/FM had significant correlation with the chilling injury index, and the result was in

accordance with the reports of Zhang et al. [19]. qNP increased under cold stress, which indicated that the non-photochemical dissipation of excessive light energy was enhanced, and it was favorable to protect the photosynthetic apparatus against the damage of cold stress. But the conclusion was inconsistent with the reports of Zhang et al. [19], and further study will be needed to verify the conclusion.

Different sugarcane genotypes had significantly different responses to low temperature. Under low temperature, chlorophyll content, net photosynthetic rate, stomatal conductance, FV/FM, ΦPSⅡ, Fv′/Fm′ and qP were decreased, ETR, Fo, Fs and qNP were increased. The chlorophyll content and photosynthetic parameters had significant correlations with the chilling injury index, especially the chilling injury index and Fv/Fm, Fv′/Fm′ and ΦPSⅡhad high correlation coefficients (high than 0.800), which indicated that Fv/Fm, Fv′/Fm′ and ΦPSⅡ could be used as the indexes of cold tolerance in sugarcane. Chlorophyll fluorescence technique could be used for determination of cold stress of sugarcane, which had no damage, stable, fast and accurate characteristics, and it would help sugarcane breeding and improve the efficiency of sugarcane breeding.

ACKNOWLEDGEMENT

This work was supported by the Basic Scientific Research Profession Fund of GXSRI (G2009012), the National Key Technology R&D Program (2008BADB8B00), National Program for International S&T Cooperation (2008DFA30600, 2009DFA30820), Guangxi Technology R&D Program (Gui Ke Chan 1123008-1), Guangxi Natural Science Foundation (2011GXNSFF018002, 2013NXNSFAA019073), and Guangxi Special Funds for Bagui Scholars and Distinguished Experts (2013).

REFERENCE

[1] Li, Y.R., and Yang, L.T., 2009, New developments in sugarcane industry and technologies in china since1990s, Southwest China Journal of Agricultural Sciences, 22(5):1469–1476.

[2] Li, Y.R., Wu, J.M., Li, X., Zhang, R.H., Liu, X.H., and Yang, L.T., 2015, Damage in sugarcane production caused by long duration of chilling and frost in Guangxi, China, International Journal of Agriculture Innovations and Research, 3(4):1139–1144.

[3] Yang, R.Z., Li, Y.R., Wang, W.Z., Zhu, Q.Z., Zhou, H., Tang, S.Y., Luo, and Y.W., 2011, Evaluation on cold tolerance of sugarcane under drought and frost conditions, Southwest China Journal of Agricultural Science, 24(1):52–57.

[4] Yang, R.Z., Li, Y.R., Wang, W.Z., Yang, L.T., Liang, T., Zhou, H., Huang, X., Luo, Y.W., and Mo, L.X, 2011, Evaluation for cold tolerance of sugarcane under rain frost condition. Southwest China Journal of Agricultural Science, 24(3):1065–1071.

[5] Deng, Z.Y., Liu, H.B., Zhang, G.M., Fang, F.X., He, H., Li, Y.R., Yang, R.Z., Li M., Chen, G.L., Liang, Z.X., and Bi, S.L., 2009, Investigation of frost bitten sugarcane in Guangxi from 2007 to 2008, Sugar Crops of China, (1):47–50

[6] Tan, H.W., Li, Y.R., Zhou, L.Q., Xie, R.L., Huang, J.S., and Huang, M.F., 2010, Influences of frosty weather on sucrose content and growth of main sugarcane varieties in the central areas of Guangxi, Guangxi Agricultural Sciences, 41(4):326–328.

[7] Zhou, Y.W., Liu, Y.P., and Dai, S.L., 2006, Identification of cold resistant plants by chlorophyll fluorescence analysis technique, Plant Physiology Communications, 42(5):945–950.

[8] Chen, J.M., Yu, X.P., and Cheng, J.A., 2006, The application of chlorophyll fluorescence kinetics in the study of physiological responses of plants to environmental stresses, Acta Agriculturae Zhejiangensis, 18(1): 51–55.

[9] Zhang, M.Q., Chen, R.K., Lu, J.L., Luo, J., and Xu, J.X., 1999, Effects of low temperature stress on the chlorophyll a fluorescence induction kinetics in the seedling of sugarcane, Journal of Fujian Agricultural University, 28(1): 1–7.

[10] Wang, G.L., and Guo, Z.F., 2005, Effects of chilling stress on photosynthetic rate and the parameters of chlorophyll fluorescence in two rice varieties differing in sensitivity, Chinese Journal of Rice Science, 19(4):381–383.

[11] Li, X., Dai, C.C., Cheng, Y., Chen, T., and Jiao, D.M., 2006, Identification for cold tolerance at different growth stages in rice (Oryza sativa L.) and physiological mechanism of differential cold tolerance, Acta Agronomica Sinica, 32(1):76–83.
[12] Gao, S.H., and Liu, L., 2007, Impact of low temperature and drought on corn photochemical conversion effect and photosynthesis process in heading stage, Meteorological Monthly, 33(4):88-91.
[13] Wang, X.N., Fu, L.S., Li, Z.F., Yang, F., Sun, Y.L., Liu, C., Wang, J.W., and Chen, Y.X., 2009, Comparison of chlorophyll fluorescence parameters between two winter wheat cultivars during cold acclimation and frozen period, Journal of Triticeae Crops, 29(1):83–88.
[14] Xi, G., Yang, C.P., Song, Q., and Chen, H.B., 2002, The changes of chlorophyll fluorescence dynamic parameters of banana and the difference of varieties under low temperature stress, Acta Photonica Sinica, 31(12):1236–1239.
[15] Xie, J.M., Yu, J.H., Huang, G.B., and Feng, Z., 2011, Correlations between changes of absorption and transformation of light energy by PSII in pepper leaves and the variety tolerance under low temperature and weak light, Scientia Agricultura Sinica, 44(9):1855–1862.
[16] Li, G.Q., Xie, Z.J., Yao, X.Q., and Chen, X.H., 2010, Studies on the relationship between chlorophyll fluorescence parameters and cold tolerance of cauliflower, Acta Horticulturae Sinica, 37(12):2001–2006.
[17] Zhou, Y.H., Huang, L.F., and Yu, J.Q., 2004, Effects of sustained chilling and low light on gas exchange，chlorophyll fluorescence quenching and absorbed light allocation in cucumber leaves, Journal of Plant Physiology and Molecular Biology, 30(2):153–160.
[18] Wang, Y.J., Zhang, H.Y., Zhang, F., Xu, Y., Cao, W.H., and Kang, G.B., 2001, Effects of low temperature and low light intensity stress on photosynthesis in seedlings of different cucumber varieties, Acta Horticulturae Sinica, 28 (3): 230–234.
[19] Zhang, S.R., 1999, A discussion on chlorophyll fluorescence kinetics parameters and their significance, Chinese Bulletin of Botany, 16(4):444–448.
[20] Ren, G.S., Cheng, J.X., Wang, H.D., Zhao, C.L., Zhang, F., Li, X.Y., and Xu, C.M., 2007, Study on the physiological response and the comparison of chilling tolerance of different eggplant varieties under the low temperature stress, China Vegetables, (4): 12–15.
[21] Wang, K.B., Zhao, F.H., Wang, X.X., and Li, S.D., 1996, In vivo chlorophyll a fluorescence induction kinetics as a tool for chilling tolerance detection in tomato, Chinese Bulletin of Botany, 13(2):29–33.
[22] Genty, B., Briantais, J.M., and Baker, N.R., 1989, The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence, Biochimica Biophysica Acta, 990: 87–92.
[23] Rizza, F., Pagani, D., Stanca, A.M., and Cattivelli, L., 2001, Use of chlorophyll fluorescence to evaluate the cold acclimation and freezing tolerance of winter and spring oats, Plant Breeding, 10:389–396.
[24] Lai, Q.X., Bao, Z.Y., Zhu, Z.J., Mao, B.Z., Qian, Q.Q., and He, Y., 2007, Effects of drought stress on photosynthesis of gerbera modified by PSAG12-ip, Acta Horticulturae Sinica, 34(1):157–162.
[25] Van Kooten, O., and Snel, J.F.H., 1990, The use of chlorophyll fluorescence nomenclature in plant stress physiology, Photosynthesis Research, 25:147–150.
[26] Feng, J.A., Hu, X.L., and Mao, X.J., 2002, Application of chlorophyll fluorescence dynamics to plant physiology in adverse circumstance, Economic Forest Researches, 20(4):14–18, 30.
[27] Ying, J., Lee, E.A., and Tollenaar, M., 2000, Response of maize leaf photosynthesis to low temperature during the grain-filling period, Field Crops Research, 68(2):87–96.
[28] Perks, M.P., Osborne, B.A., and Mitchell, D.T., 2004, Rapid predictions of cold tolerance in Douglas-fir seedlings using chlorophyll fluorescence after freezing, New Forests, 28(1):49–62.
[29] Li, G.J., Liu, Y.H., Wu, X.H., Wang, B.G., and Zhong, F., 2005, Relationship between the tolerant ability to low temperature and low light intensity and chlorophyll fluorescence in seedlings of asparagus bean, Acta Agriculturae Zhejiangensis, 17(6):359–362.