ORIGINAL PAPERS

The growth and chlorophyll fluorescence characteristics of *Pinus caribaea* and *P. elliottii* at the seedling stage

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Abstract The nutrition pot experiments of *Pinus caribaea* and *P. elliottii* (PEE) were conducted to assess the response of chlorophyll (Chl) fluorescence parameters to different provenances and measured time. The materials were potted seedlings from 16 *P. caribaea* provenances and 4 PEE provenances. The growth of the seedlings and the Chl fluorescence parameters were measured in July and August 2016 and February 2017, separately. The result showed there were significant differences among seedlings of different provenances in height and diameter (P<0.01). The measured time and species had a significant effect on the PSⅡ maximal photochemical efficiency (Fv/Fm), while the interaction effect was not significant. The Fv/Fm was higher in February 2017 than in July 2016 and August 2016; the response models of measured times of two species were opposite in the effective quantum yield (ΦPSⅡ), the photochemical quenching coefficient (qP) and the apparent electron transport rates (ETR). The Chl fluorescence parameters of two species were affected by the measured times rather than provenances. The growth had a negative correlation with Fv/Fm and Fv′/Fm′ in February 2017 in examined seedlings according to the correlation analysis. The Chl fluorescence parameters of *P. caribaea* and PEE were inhibited by high light intensity, which might not affect the growth. The Chl fluorescence parameters in *P. caribaea* were also inhibited by low temperature, which might be related to growth. The Chl fluorescence parameters of *P. caribaea* in February 2017 might be indicators of chilling tolerance among *P. caribaea* individuals.

Keywords *Pinus caribaea* · *Pinus elliottii* · Growth · Traits chlorophyll fluorescence parameters

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Introduction

Pinus caribaea, a tree native to North America, has three variants: PCC (*P. caribaea* var. *caribaea*), PCH (*P. caribaea* var. *hondurensis*) and PCB *(P. caribaea* var. bahamensis) (Farjon & Styles, 1997). *P. caribaea* is an important commodity tree species in the tropical region because of its fast growth, good branching habits, and resistance to drought (Li et al. 2015; Guo et al. 2016). *P. elliottii* is native to the southeastern United States warmed moist low-lying areas (Zhou et al. 2012). It is adaptable to drought and infertile soil with high survival rate of afforestation, achieving high yield, good wood quality, and high economic return for cultivation, it is one of the main cultivars growing in south China (Li et al. 2012; Wei et al. 2016).

The photosynthesis of plants is the basis of organic matter synthesis, energy storage and transformation (Rozendaal et al. 2006; Dong et al. 2012; Wang, 2015), highly depending on light condition. The photosynthetic characteristics of plants vary with the specificity and adaptability of different provenances. Available chlorophyll fluorescence kinetics can be rapid and sensitive, noninvasive optical system reflects Ⅱ (PSⅡ) on absorption of light energy to be transmitted, dissipated and distributed in other ways (Zhao et al. 2006; Hentiques, 2003). Previous studies found that the maximum energy conversion efficiency of PSⅡ(Fv/Fm), photochemical quenching (qP), the apparent quantum transport rate (ETR) for *Rhus chinensis* gradually decreased with the extension and severe drought in summer(Wang, 2008). The Fv/Fm, Fv′/Fm′, qP, Φ PSⅡ and ETR of *P. sylvestris* were negatively correlated with the degree of salt stress (Zhang et al. 2008). Currently, there are few studies on the photosynthesis and chlorophyll fluorescence kinetics of pine trees (Wang et al. 2016). In this paper, 16 provenances of *P. caribaea* with three varieties and 4 provenances of *P. elliottii* were selected, and the chlorophyll fluorescence parameters were measured in Guangzhou. The aim of this study was to examine the differences in chlorophyll fluorescence characteristics between *P. caribaea* and *P. elliottii* with different provenances. The findings from this study will provide insight into species selections for fast - growing and cold - tolerant provenances of the two major species in this region.

Materials and methods

Study area

This study was done in the nursery of Guangdong Academy of Forestry, which is located in subtropical monsoon climate zone (23°20′ N, 113°20′ E), with an average annual temperature of 21.8 ℃, the absolute maximum temperature of 38.1℃, and the absolute minimum temperature of 0 ℃; The annual precipitation is 1 694 mm.

Study materials and experimental design

The test materials included a total of 16 provenances from the three variants of *P. caribaea*, wherein 1-10#, 12#, 18# are PCH. 1-10# were introduced from Honduras natural forests, 12# from Australia seed garden, and 18# from Brazil seed garden; 11#, 13 #, 17 # were PCC, 11# was originated from natural forests in Cuba, 13# from Zhanjiang seed garden, and 17 # from Brazil seed garden, respectively; 16# was PCB, cited in Brazilian seed garden. 4 provenances of PEE were 21 #, 22 #, 24 #, 25 #, from Taishan Hongling seed garden, nursery in Suixi county, Florida seed garden, and Georgia seed garden, respectively. The test seeds were sown in September 2014, and was grown on non-woven bag of 30 cm diameter (yellow soil as a substrate), the spacing of 30 cm × 30 cm in August 2015.

Test methods

A rare cold wave in late January 2016, in Guangzhou had a chilling injury to the seedling growth in the nutritious bags. In March, 2016, the growth gradually recovered. In January 2017, the weather was relatively mild, seedlings did not show significant chilling injury in Guangzhou.

The plant height (cm) and collar diameter (mm) of seedlings were investigated for each sample of the *P. caribaea* / *P. elliottii* plants using the electronic vernier calipers and ruler in the late May of 2016 and in the first half of 2017.

Chlorophyll fluorescence was measured in late July to early August in 2016 and early February in 2017. The chlorophyll fluorescence parameters of the leaves were determined by the portable photosynthesis system (Li-6400-XT, Li- COR, USA) with the modulated fluorescent leaf chamber (Li-6400-40). Four healthy individuals were selected for each provenance. As 13#, 17# grows slowly, their chlorometric analysis of the chlorophyll fluorescence properties were not carried out. For the rest provenances, at the time of 18:00 the day before the determination, the sunning branches of the second turn of the tree were selected, and four bundles of needles were wrapped with tin foil, and the leaves remained dark overnight. The next day at 8: 30–17: 30, several chlorophyll fluorescence parameters were first measured to represent the dark adaptation, then activate light (1 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$) for 20 min, the corresponding parameters were recorded again to determine the light adaptation. The analysis parameters include the initial fluorescence (Fo), the maximal fluorescence (Fm), the maximum energy conversion efficiency of PSⅡ (Fv/Fm), the minimum light fluorescence yield (Fo′), the maximal fluorescence light (Fm′), photochemical quenching (qP), non-photochemical quenching (NPQ), PSⅡ effective photochemical efficiency (Fv′/ Fm′), the actual quantum yield (Φ PSⅡ) and the apparent quantum transport rate (ETR) . Detail is described by Zhang et al. (2014).

Data analysis

Microsoft excel 2010 and SAS 9.4 software was used for statistical analysis of test data.

Results

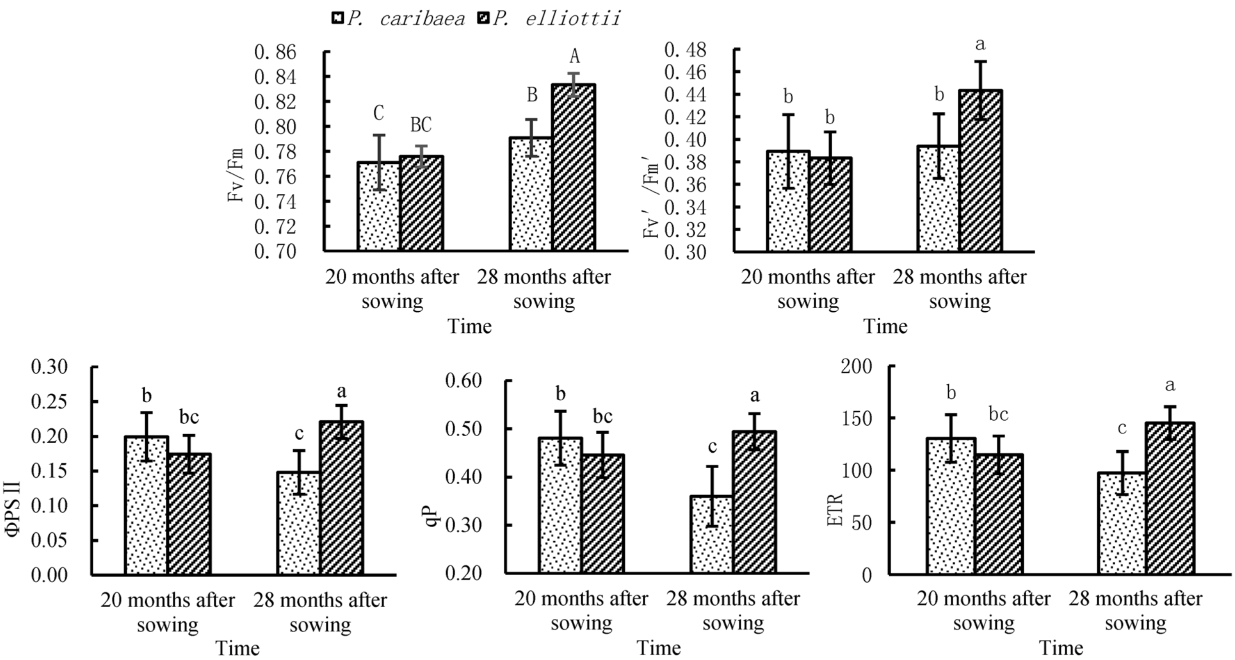
Seedling growth among different provenances for *P. caribaea* and *P. elliottii*

There were significant differences ($P<0.01$) in plant height and diameter growth of different provenances of *P. caribaea* and *P. elliottii* (Table 1). Three variants of *P. caribaea* are generally large in size. The growth of PCH was significantly higher than that of PCC, PCB. Except 12 #, 2 #, the remaining 10 provenances from PCH generally grew fast. The average plant height of PCH seedling was 63.26 cm and the collar diameter was 13.06 mm at 20 months after sowing. The average plant height

Table 1 20 provenances seedling growth of *P. caribaea* and *P. elliottii*

Species	Variant	Provenance	20 months after sowing		28 months after sowing	
			Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
P. caribaea	PCH	1#	68.45±14.17	15.34±3.70	101.80±18.88	28.42±6.95
P. caribaea	PCH	2#	49.96±16.04	10.14±4.17	87.52±21.70	20.83±7.33
P. caribaea	PCH	3#	66.00±12.05	13.83±3.07	101.24±19.93	24.45±5.58
P. caribaea	PCH	4#	63.36±13.96	11.78±3.61	108.02±22.20	24.34±6.18
P. caribaea	PCH	5#	63.55±13.33	13.25±3.68	109.34±21.87	27.40±6.22
P. caribaea	PCH	6#	66.35±11.64	13.56±3.30	108.50±16.75	27.15±6.86
P. caribaea	PCH	7#	56.93±12.04	13.44±3.71	99.60±20.27	25.46±5.97
P. caribaea	PCH	8#	60.52±15.79	11.99±3.61	105.46±25.08	24.56±7.27
P. caribaea	PCH	9#	62.89±13.52	13.64±2.93	99.79±20.55	24.15±6.44
P. caribaea	PCH	10#	64.18±13.86	12.13±2.94	103.97±22.32	22.86±6.49
P. caribaea	PCH	12#	41.79±12.33	7.86±2.99	75.35±20.16	16.86±6.14
P. caribaea	PCH	18#	60.36±18.03	11.67±4.50	103.58±23.44	23.88±7.12
P. caribaea	PCC	11#	39.50±9.75	6.75±1.74	64.89±18.62	12.13±3.08
P. caribaea	PCC	13#	13.60±6.93	2.67±1.47	27.92±14.76	5.85±2.63
P. caribaea	PCC	17#	11.47±4.30	2.28±0.70	20.08±9.22	3.74±1.64
P. caribaea	PCB	16#	37.82±10.07	8.20±1.79	79.67±22.76	15.17±3.88
P. elliottii		21#	35.67±14.50	6.50±2.65	55.33±22.89	14.26±5.68
P. elliottii		22#	45.67±16.20	8.37±3.26	71.98±24.47	17.28±7.20
P. elliottii		24#	58.62±11.82	10.84±2.10	83.26±20.19	21.86±6.05
P. elliottii		25#	63.53±13.59	10.56±2.36	87.81±18.29	21.97±6.21

Note: The data in the table is the mean ± s.d. The seeding time is September 2014.



Note: The y-axis values are the least squares (Lsmeans) and and error bars are the standard errors. Same lowercase or uppercase letters on the columns indicate no significant difference between tree species at the levels of 0.05 or 0.01, respectively. The two species were seeded in September 2014.

Figure 1 Variations in Chlorophyll fluorescence parameters of *P. caribaea* and *P. elliottii* over time since seeding

Table 2 Correlation between growth and chlorophyll fluorescence parameters for *P. caribaea* and *P. elliottii* in February

Species	Age	Index	*R*					
			Fv/Fm	Fv′/Fm′	ΦPSII	qP	NPQ	ETR
P. caribaea	20 months after sowing	Hight	0.255	−0.025	−0.001	0.017	0.390*	−0.001
		Diameter	−0.363*	−0.327*	−0.154	−0.064	−0.227	−0.168
	28 months after sowing	Hight	−0.075	−0.316	−0.07	0.078	0.277	−0.071
		Diameter	−0.164	−0.251	−0.143	−0.02	0.038	−0.156
P. elliottii	20 months after sowing	Hight	−0.649*	−0.660*	−0.34	0.047	0.477	−0.321
		Diameter	−0.464	−0.562	−0.237	0.115	0.481	−0.214
	28 months after sowing	Hight	−0.556	−0.506	−0.218	0.094	0.295	−0.193
		Diameter	−0.558	−0.379	−0.008	0.311	0.105	0.015

Note: "*" Indicates a significant correlation at 0.05 level.

reached 104.14 cm with the diameter of 25.27 mm after 28 months. Seedlings of PCC variants show lower growth than that of PCH although 11 # provenances grew relatively fast. 13 # and 17 # provenances were the worst among 16 provenances of *P. caribaea* in plant heights and collar diameters, which was much lower than that of *P. elliottii*. In contrast, 16 # from PCB had a significantly higher growth than any variants of PCC, and grew overpassing 12 # of PCH after 28 months of sowing. 21 #, 22 # seedling of PEE grew relatively comparable to that of some PCH until within 20 months after sowing but declined relative to PCH after 28 months since seeding (Table 1).

Differences in chlorophyll fluorescence parameters of *P. caribaea* and *P. elliottii*

The light energy conversion efficiency (Fv/Fm) of the maximum PS Ⅱ of chlorophyll fluorescence varied over growing course (Figure 1), significantly higher in February than in July and August for both *P. elliottii* and *P. caribaea*. The Fv/Fm of *P. elliottii* in February was significantly higher than that of *P. caribaea*, but the differences were observed in July and August. The Fv′/ Fm′ value of *P. elliottii* in February was significantly higher than that of *P. caribaea* in the same period, and was also significantly higher than that of the two species in July and August. ΦPSⅡ, qP and ETR showed a consistent trend with the change of measurement time and species. However, the ΦPS Ⅱ, qP and ETR were significantly higher in July and August than in their corresponding values in February. In contrast, the ΦPSⅡ, qP and ETR were significantly lower for *P. elliottii* than those for *P. caribaea* in February. Significant differences in the Fv/Fm were found between *P. caribaea* and *P. elliottii*, suggesting the variations in the photochemical mechanism of light system Ⅱ with coniferous species.

Variations in chlorophyll fluorescence parameters among different provenances for *P. caribaea* and *P. elliottii*

Measuring time has a significant effect on the Caribbean pine ΦPSⅡ, qP ($P < 0.01$). Except for 12 #, ΦPSⅡ for all provenances were higher in July and August than in February while the qP for all the provenances were higher in July and August then in February (Fig. 2). However, there was difference of interactions in Fv/Fm, Fv′/ Fm′, NPQ and ETR among measuring time, provenances and their interactions. The significant differences in Fv/Fm, Fv′/ Fm′ were found only among four provenances (21#, 22#, 24#, 25#) ($P<0.01$). That is there was a significant difference in the Fv′/ Fm′ measured in February between 22# and 25#.

Relationship between seedling growth and chlorophyll fluorescence characteristics of needle

Twenty months since seeding and height growth for *P. elliottii* showed some negative correlation with February Fv/Fm, Fv′/ Fm′ measurements with the correlation coefficient of −0.649 and −0.660, respectively (Table 2, Table 3). The height was weakly related to NPQ for *P. caribaea* (R = 0.390). The growth of plant height did not show any correlation with the chlorophyll fluorescence in July and August. Similarly, no significant positive correlation was found between seedling and chlorophyll fluorescence parameters stage after 28 months of sowing. There was a significant negative correlation between the height of *P. caribaea* and the ΦPSⅡ and ETR in July and August.

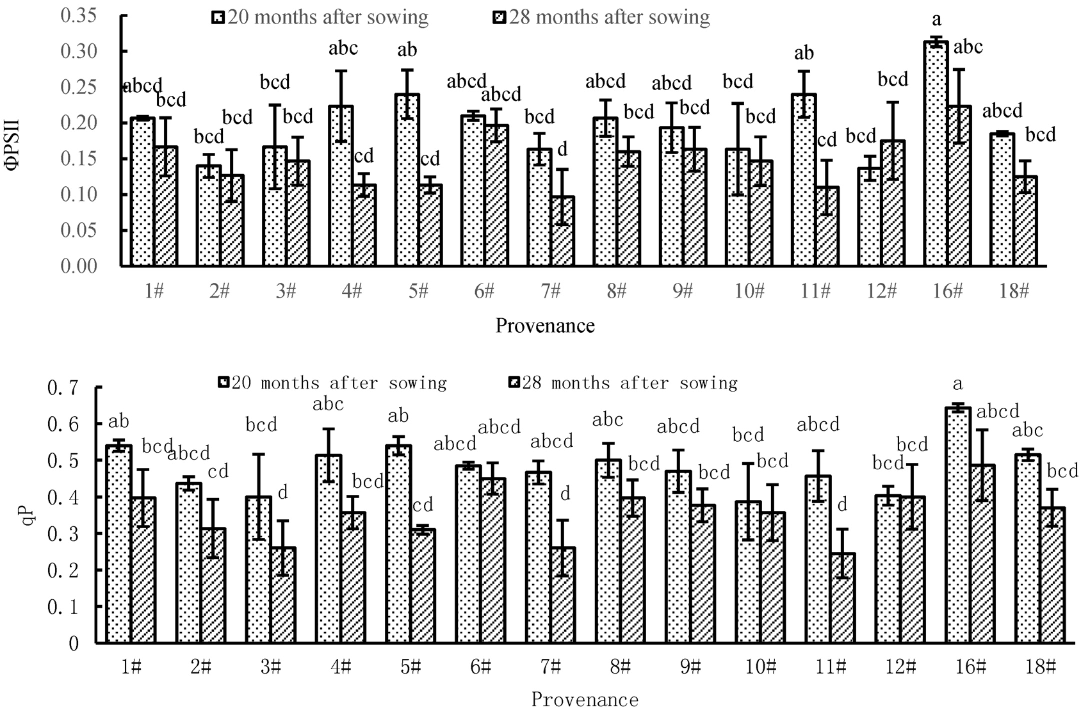
Conclusion and discussion

Plant height and diameter growth significantly varied with provenances of *P. caribaea* and *P. elliottii*. Except for 12 #, 2 #, the rest provenances from PCH are determined as rapid-growth seed sources, which is consistence with previous studies (He, 2007) although they are weak in cold resistance. Compared with PCC, the seedling growth of 16# of PCB grew fast. This is related to the difference in the time of the peak of the growth

Table 3 Correlation between growth and chlorophyll fluorescence parameters for *P. caribaea* and *P. elliottii* in July to August

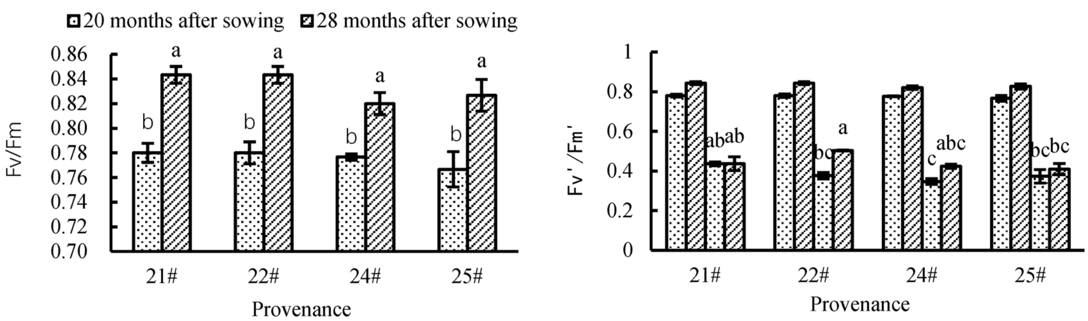
Species	Age	Index	*R*					
			Fv/Fm	Fv′/Fm′	ΦPSII	qP	NPQ	ETR
P. caribaea	20 months after sowing	Height	−0.262	−0.092	−0.240	−0.122	−0.055	−0.233
		Diameter	0.033	−0.178	−0.158	0.009	−0.018	−0.159
	28 months after sowing	Height	−0.202	−0.181	−0.326*	−0.094	0.198	−0.327*
		Diameter	−0.077	−0.125	−0.221	−0.049	−0.039	−0.213
P. elliottii	20 months after sowing	Height	−0.224	−0.422	−0.31	−0.204	0.38	−0.303
		Diameter	−0.23	−0.547	−0.379	−0.257	0.366	−0.376
	28 months after sowing	Height	−0.294	−0.439	−0.311	−0.196	0.286	−0.307
		Diameter	−0.456	−0.423	−0.246	−0.124	0.297	−0.234

Note: The data in the table is the mean ± s.d. The seeding time is September 2014.



Note: The y-axis values in the figure are the least squares (Lsmeans) and error bars are the standard errors. The same lowercase letters on the column indicate no significant difference in the determination of the same tree species at 0.05, respectively. The two species were seeded in September 2014.

Figure 2 Differences in Chlorophyll Fluorescence Parameters among provenances of *P. caribaea*



Note: The y-axis values in the figure are the least squares (Lsmeans) and the error bars are the standard errors. The same lowercase letters on the column indicate no significant difference in the determination of the same tree species at 0.05, respectively. The two species were sown in September 2014.

Figure 3 Provenance differences of Chlorophyll fluorescence parameters for *P. elliottii*

of different provenances (He, 2007). Early studies also show that 16 # have no obvious chilling injury phenotype after the frost damage. Therefore, it can be used as a further breeding material of *P. caribaea* and cold provenances fast-growing. There were significant differences in the growth of four provenances of *P. elliottii*, 24 # and 25 # grew faster than 21 # and 22 #. It should be noted that the seedling growth varied greatly with provenances and variants between *P. caribaea* and *P. elliottii*. Therefore, it is necessary to further explore the phenotype and the photosynthetic physiological mechanism of *P. caribaea* and *P. elliottii*.

Regardless of *P. caribaea* and *P. elliottii,* their chlorophyll fluorescence parameters in February were affected by the measure of time, and varied with species. In theory, coniferous species photosynthesis is active throughout the year, under normal growth, needles Fv/Fm values should be at least 8.0 (Gielen et al. 2000). However, for both *P. elliottii* and *P. caribaea* the Fv/Fm measured in July, August were less than 8.0, the average measured value of Fv/Fm in February for *P. caribaea* is also below 8.0. This suggests that the two species in July, August and the *P. caribaea* in February suffered environmental stress. Fv/Fm in spring and autumn was significantly larger than that in winter and summer, which may be subject to environmental stress in winter and summer (Chen et al. 2011; Zhao et al. 2013). It was also found that high radiation would inhibit the Fv/Fm value of the *P. sylvestris* conifer in other conditions (Sánchezgómez et al. 2006). The light intensity of 1 500 – 2 000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in the daytime of July and August in Guangzhou will be consistent with that of *P. elliottii* and *P. caribaea*, which is consistent with the previous research results (Sánchezgómez et al. 2006). In July and August, the chlorophyll fluorescence parameters of *P. caribaea* and *P. elliottii* were not very different, which might be similar to that of the two species. The Fv/Fm and Fv′/ Fm′ measurements in February were significantly higher than those in July and August, indicating that the stress caused by high light intensity in Guangzhou could be more severe than that caused by low temperature in February. In February, the Fv/Fm, Fv′/ Fm′, ΦPS Ⅱ, qP, ETR of *P. elliottii* were significantly larger than those of *P. caribaea*. This is due to *P. caribaea* is a tropical species, it is suitable for planting in our country to the north to 23°N (Zhong, 2008). The low temperature in February caused a degree of coercion to *P. caribaea* to a certain extent. The adaptability of *P. elliottii* in China can be distributed to 33° – 20° N. The effect of low temperature on wet slop in February is relatively small. In addition, ΦPS Ⅱ, qP, ETR parameters showed significant interaction between time and tree species, indicating that the responses of the two species to high light intensity and low temperature are different.

The Fv/Fm, Fv′/ Fm′, NPQ, ETR were not significantly affected by the measured time and provenance, and the chlorophyll fluorescence characteristics of different provenances were not significantly vary. The ΦPS Ⅱ and qP were significantly larger than those in July and August, and the response to temperature change was consistent. The Fv/Fm and Fv′/ Fm′ of the four provenances of *P. elliottii* in February were more than those in July and August, and the difference of Fv′ / Fm′ of 21# was smaller. The differences in chlorophyll fluorescence parameters between the tree species showed that the responses of *P. elliottii* and *P. caribaea* were not consistent with the stress. Previous studies have found that chlorophyll fluorescence parameters of the same species are mainly affected by the environment (Hu, 2007; Weng et al. 2013). There was no significant difference between the two species in this study. The difference between the provenances was not significant, which was consistent with the previous results. The chlorophyll fluorescence parameters of the tested materials may be affected by genotype relatively small.

Fv/Fm and other chlorophyll fluorescence parameters are generally not related to growth, only related to stress (Wei, 2007). In this study, the growth of *P. caribaea* and *P. elliottii* was significantly correlated with the chlorophyll fluorescence parameters in February, due to the weak cold tolerance of fast-growth provenances. The growth in May 2016 may be affected by the cold spells in late January 2016. The temperature is relatively low in February 2017. Measured indicators can reflect the effects of low temperature. Therefore, the measured parameters in February 2017 were strongly correlated with the growth in May 2016 (Fang, 2011). It is considered that the chlorophyll fluorescence parameters measured in February will be used as the screening index for *P. caribaea*. There were no significant correlations between Fv/Fm and other parameters measured in July and August. This is because the high light intensity has no effect on the growth of *P. caribaea* and *P. elliottii*. The ΦPS Ⅱ and ETR measured in August were negatively correlated with individual growth. It is considered as a photosynthetic physiologic index for screening good individuals grown in *P. caribaea*.

Reference

Chen C, Liu GH, Zhao HY, et al (2011) Chlorophyll Fluorescence Characteristics of *Machilus Leptophylla*. Journal of Northeast Forestry University 39(10): 50-53

Dong Q, Tang XG, Wang J, et al (2012) Comparison and cluster analysis of photosynthetic parameters of *Pistacia chinensis* in different provenances. Journal of Agricultural University of Hebei 35(3): 58-62

Fang LY (2011) Effects of Salt Stress on Photosynthesis and Salt Tolerance Estimate of *Pinus Silvestris* L. Harbin: Northeast Forestry University

Farjon A, Styles BT (1997) Flora Neotropica *Pinus* (Pinaceae). New York: The New York Botanical Garden

Gielen B, Jach ME, Ceulemans R (2000) Effects of season, needle age, and elevated atmospheric CO_2 on chlorophyll fluorescence parameters and needle nitrogen concentration in scots Pine (*Pinus sylvestris*). Photosynthetica 38(1): 13-21

Guo WB, Zhao FC, Rong JQ, et al (2016) Effects of fertilization on growth of eight-year-old Caribbean pine in West Guangdong. Journal of South China Agricultural University 37(4): 18-24

He XY (2007) Studies on Genetic Diversity of *Zenia Insignis* Provenances and Their Resistance to Low Temperature Stress. Changsha: Central South University of Forestry and Technology

Henriques FS (2003) Gas exchange, chlorophyll a fluorescence kinetics and lipid peroxidation of pecan leaves with varying manganese concentrations. Plant Science 165(1): 239-244

Hu XJ (2007) Studies on the Seedling Physiological Characteristics in Different *Pinus Massoniana* Provenance under Drought Stress. Nanjing: Nanjing Forestry University

Li YJ, Jiang JM, Luan Q F (2012) Determination and genetic analysis of resin productivity, resin density and turpentine content in half-sib families of slash pine. Journal of Beijing Forestry University 34(4): 48-51

Li YL, Zhao FC, Lin CM, et al (2015) Selection of Superior Trees of *Pinus elliottii* and *P. caribaea* in Plantation. Guangdong Forestry Science and Technology 31(6): 29-34

Rozendaal D, Hurtado VH, Poorter L (2006) Plasticity in leaf traits of 38 tropical tree species in response to light; relationships with light demand and adult stature. Functional Ecology 20(2): 207-216

Sánchezgómez D, Valladares F, Zavala MA (2006) Functional traits and plasticity in response to light in seedlings of four Iberian forest tree species. Tree Physiology 26(11): 1425-1433

Wang H (2008) Study on the Photosynthesis Characteristics and Relative Physiological Index of Red-Leaf Peach under Drought Stress in Summer and Autumn. Nanjing: Nanjing Forestry University

Wang PL. The Researches on Seed Quality and Seedling Growth Characteristics of *Castanopsis Tibetana* from Different Provenances. Changsha: Central South University of Forestry and Technology, 2015

Wang Q, Nie X, Liu XM, et al (2016) Photosynthetic characteristics and chlorophyll fluorescence of three Pinus tree species with shading. Journal of Zhejiang A & F University 33(4): 643-651

Wei LD, Tang SS, Wei J X, et al (2016) The Growth Rules of Slash Pine Plantation. Guangxi Forestry Science 45(3): 276-279

Wei X (2007) Study on Leaf Gas Exchange and Chlorophyll Fluorescence in *Pinus Massoniana* of Restoring Ecosystems in Changting County of Fujian Province. Fuzhou: Fujian Normal University

Weng J, Ruan SN, Huang SY, et al (2013) Drought assessment on different provenances of Acaciamelanoxylon. Fujian Forestry 167(4): 25-27

Zhang AH, Qi MW, Zhang YH (2008) A Discussion on Chlorophyll Fluorescence Induction Parameters and their Measurement. Journal of Nuclear Agricultural Sciences 22(6): 909-912

Zhang YL, Zhang WQ, Gan XH (2014) Influence of low temperature stress on the photosynthetic fluorescence characteristics of 6 kinds of precious hardwoods seedling in winter. Ecology and Environmental Sciences 23(5): 777-784

Zhao HY, Liu GH, He XD, et al (2013) Chlorophyll Fluorescence Characteristic of Seedlings of *MangLietia yuyuanensis*. Journal of Northeast Forestry University 41(3): 1-5

Zhao T, Gao ZK, Xu GH, et al (2006) Study On Getting Parameters of Chlorophyll Fluorescence Dynamics by Non- Modulated Fluorometer Plant Efficiency Analyser. Acta Biophysica Sinica 22(1): 34-38

Zhong WH (2008) The Practice and Exploration in Forest Genetics and Tree Breeding — Zhong Weihua's Selected works. Guangzhou: Guangdong Science & Technology Press, LTD

Zhou J, Wei H, Lv Q, et al (2012) Effects of soil water regime on leaf photosynthetic characteristics of slash pine (*Pinus elliottii* Engelm.) seedlings. Chinese Journal of Ecology 31(1): 30-37