

## EFFECTS OF ANTHOCYANINS ON FUNCTIONS OF PHOTOSYNTHESIS SYSTEM IN THREE SYRINGA LEAVES UNDER LOW LIGHT CONDITIONS

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(Received 28<sup>th</sup> Jul 2021; accepted 26<sup>th</sup> Jan 2022)

**Abstract.** In this study, taking *Syringa oblata* Iandl (SI), *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) as the test material, the functional role of anthocyanins in photosynthetic apparatus in leaves of three varieties under different light conditions were investigated. In the low light,  $P_n$ ,  $G_s$  and  $T_r$  values of *Syringa* leaves decreased. Meanwhile, minimal fluorescence ( $F_o$ ), maximum fluorescence ( $F_m$ ) and absorption flux per reaction center ( $ABS/RC$ ) in young leaves of SI was lower than those of SL and SC, which indicated that anthocyanins could reduce the absorption of light in *Syringa* leaves. Furthermore, the parameters of PSII photochemical efficiency ( $F_v/F_m$ ), PSII potential activities ( $F_v/F_o$ ), electron transport rate ( $ETR$ ) and actual photochemical efficiency ( $\Phi_{PSII}$ ) of SI was higher than that of SL and SC in low light, respectively. The number of PSII reactive center,  $ABS/RC$ , maximal trapped energy flux per reaction center ( $TR_o/RC$ ), electron transport flux per reaction center ( $ET_o/RC$ ) and dissipated energy flux per reaction center ( $DI_o/RC$ ) of SL and SC were significantly higher those of SI in low light, while the proportion of inactivation of reactive center in SL and SC were higher than others in low light.

**Keywords:** *Syringa*, anthocyanin, PSII, chlorophyll fluorescence, OJIP

### Introduction

Anthocyanin is an important water-soluble compound, which drives from glycosylation derives of anthocyanidin through combining different monosaccharides with glucosidic bond. The chemical species play functions as osmotic adjustment substances in abiotic stresses such as high light, low temperature and strong UV-light. Most salient among the flavonoids were the anthocyanins-universal plant colorants presented the red, purple, and blue hues apparent in many fruits, vegetables, cereal grains, and flowers. Some plant species show red leaves, this is mainly due to the accumulation of anthocyanins that covered the green chlorophyll reflectance, although accumulation was usually transient (Gould et al., 1995). Leaf anthocyanins have positive effects on various damages caused by photooxidation (Gould et al., 2002), UV-B radiation (Lindoo and Caldwell, 1978; Mendez et al., 1999), and pests and diseases (Hamilton et al., 2001; Karageorgou and Manetas, 2006). Particularly anthocyanins can protect photosynthetic apparatus against high light and alleviate photoinhibition. The Anthocyanin has a strong absorption in the visible spectrum between 400 nm and 600 nm. Similar as photosynthetic pigments, anthocyanins in vegetative tissues preferentially absorb green and ultraviolet light and present lower absorbance of blue light, while little absorbance of red light. The absorption characteristics of anthocyanins has potential roles in consumption of excess light captured by leaf chlorophyll. The

accumulation of anthocyanins disturbs efficiency of leaf absorption to light energy, and the distribution of light energy in the photosynthetic apparatus. In recent years, light regulation on anthocyanin synthesis during photomorphogenesis have been widely studied by molecular and Chlorophyll fluorescence tools (Burger and Edwards, 1996; Dodd et al., 1998). Anthocyanin, the PSI and the PSII synthesis were regulated by the phytochrome-mediated activation of their respective signal transduction pathways. Synthesis of anthocyanins and lack of chlorophyll have significant impacts on leaf photosynthesis of many plant species in seedling period, which seedlings are susceptible to light-induced stress. Pietrini and Massacci (1998) found that anthocyanins in red leaves reduced the photosynthetically active radiation reaching the chloroplasts by 40%. Anthocyanin accumulation in leaves also protected the mesophyll cells (Chalker-Scott, 1999), reduced photoinhibition (Hughes and Smith, 2007) and photo-oxidative damage (Steyn et al., 2002) through filtering or attenuating high-power blue-violet with excess solar energy. Short-term cold spells or long-term seasonal low temperature can also induce anthocyanin synthesis. Anthocyanin synthesis is coincided with recovery of photosynthetic activity in cold environments. An increasing accumulation of anthocyanin might be an adaptive response of plants to low temperature. Low temperature has an even greater effect on carbohydrate metabolism by limiting assimilate utilization. Anthocyanin accumulation probably protected the plant tissues exposed to low temperature/light combined stress against photoinhibition.

*Syringa* has a tree shape, elegant flower color, dense inflorescence, red fruit in early autumn, with high ornamental value, and *Syringa* has a strong cold resistance, *Syringa oblata* Iandl (SI), *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) can be cultivated in the northern of China. Especially *Syringa oblata* Iandl (SI) having purple-red leaves due to anthocyanin accumulation, are important ornamental plants both for flower and foliage (Liu et al., 2010; Xie et al., 2006). However, *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) has green leaves, with very little anthocyanin content in leaves. In the present study, we studied chlorophyll fluorescence parameters of of three *Syringa* species by using the chlorophyll fluorescence technique, and analyzed the effects of anthocyanin accumulation on light absorption, distribution, conversion and electron transfer in photosynthesis processes in natural light and low light. The aim of this study was to reveal the function of anthocyanin in photosynthesis.

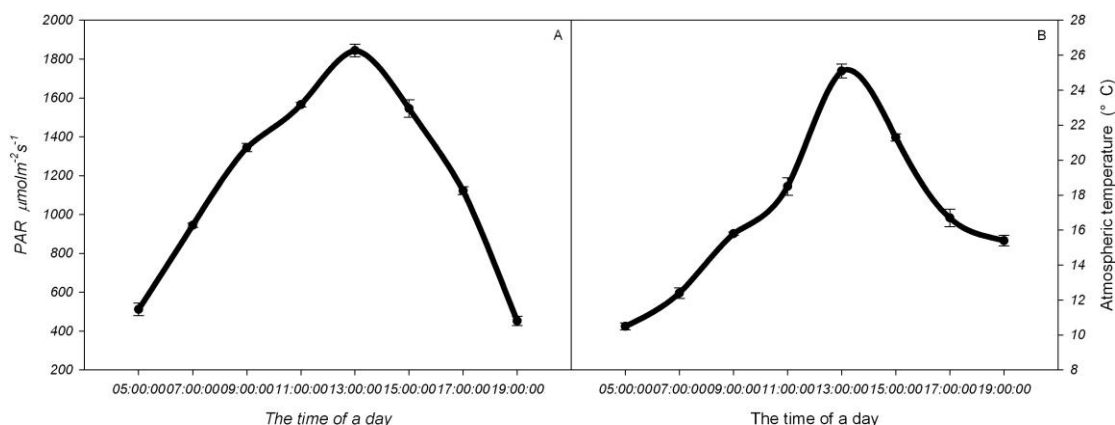
## Materials and methods

### *Plant material and growth conditions*

The seedlings of *Syringa oblata* var. *affinis* Lingelsh (SL), *Syringa oblata* Iandl (SI) and *Syringa chinensis* (SC) were provided by Jilin Agricultural University in August 2019. The leaves of *Syringa oblata* Iandl (SI) rich in Ant were purple-red, but the leaves of *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) were all green growing under natural light. The three *Syringa* species were all triennial and 1.5 m height. There were not shaded by shrubs.

Three *Syringa* species were collected for measurement of photosynthetic parameters: Five cuttings of each species were cultivated indoors under an artificial lamp (Microwave sulfur lamp-N1, Suzhou, China) with a lighting intensity of  $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . The other seedlings remained under an outdoor natural. The diurnal variation of photosynthetic active radiation (PAR) and temperature were shown in *Figure 1*. The PAR and temperature were lower in the morning, in particular atmospheric temperature had been

below 10 °C, which was made a significant effect on photosynthetic apparatus in plant leaves. But at noon, temperature and PAR was still very strong, especially the PAR reached 1800  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ , while the lower the temperature of the environment in the autumn, so light intensity could easily lead to photoinhibition of leaves. Plants under low light or natural light were watered in the same manner, and fertilizers were not applied.



**Figure 1.** Diurnal change of PAR and temperature in Jilin Agricultural University in August 2019. Data in the figure are mean  $\pm$  SD

### Determination of photosynthetic gas exchange parameters

The net photosynthetic rate ( $P_n$ ), stomatal conductance ( $G_s$ ), transpiration rate ( $T_r$ ) and intercellular  $\text{CO}_2$  concentration ( $C_i$ ) of the second fully expanded functional leaf of *Syringa* were measured at 9:00-11:00 a.m. by using Li-6400 photosynthetic measurement system (Licor company, USA). The PFD was provided by the instrument's light source at 1200  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ , and  $\text{CO}_2$  concentration was fixed at 400  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  using  $\text{CO}_2$  cylinder. The process was repeated 5 times.

### Chlorophyll and anthocyanin contents

Contents of Chlorophyll, Chlorophyll 'a' and 'b' were determined by the method of Inskeep and Bloom (1985). Anthocyanin content was measured by the method of Pirie and Mullins (1976).

### Chlorophyll fluorescence measurements

We measured the chlorophyll fluorescence parameters ( $F_m$ ,  $F_o$ ,  $F_v/F_m$ , and  $F_v/F_o$ ) of the natural light and low light leaves by using a portable pulse amplitude modulation fluorometer (PAM-2000, Walz, Effeltrich, Germany) according to the method of Hu et al. (2007). Apparent electron transport rate ( $ETR$ ) and actual photochemical efficiency ( $\Phi_{\text{PSII}}$ ) of the leaves were determined at nature light (about 1200  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ). We also measured light absorption and characteristic parameters of PSII reaction center by the method of Hendrickson (2008) and Zhou (2007), including quantum yield of photochemistry ( $\Phi_{\text{PSII}}$ ); quantum yield of trans-thylakoid pH gradient and xanthophyll-regulated thermal energy dissipation ( $\Phi_{\text{NPQ}}$ ); quantum efficiency of fluorescence and constitutive thermal dissipation ( $\Phi_{\text{FD}}$ ); and quantum yield of thermal dissipation associated with the presence of non-functional PSII ( $\Phi_{\text{NF}}$ ).

A fluorescence induction transient (OJIP) of the low light leaves and natural light leaves were determined by the mini hansatech fluorescence monitoring system (FluorPen FP 100max, Czech). It can get absorption flux per reaction center ( $ABS/RC$ ), rapped energy flux per reaction center ( $TR_o/RC$ ), electron transport flux per reaction center ( $ET_o/RC$ ), and dissipated energy flux per reaction center ( $DI_o/RC$ ). All the above measurements were performed during 9:00 am – 11:00 am, with five replications (Hendrickson et al., 2004).

### ***Determination of OJIP curve***

The leaves of different treatments were dark adapted for 0.5 h, then the leaves on the new shoots were selected to fully expand. The OJIP curve was measured by mini modulation palmtop chlorophyll fluorescence meter (fluoropen FP 100 max, Czech Republic), and the fluorescence intensity ft of each time point on the OJIP curve was used to draw the curve.

### ***Statistical analysis***

Excel and SPSS software (Version. 22) were used to conduct statistical analyses on the measured data. The data in the figure was denoted as mean  $\pm$  standard deviation (SD). One way ANOVA and least significant difference (LSD) were used to compare the differences among different data groups.

## **Results and analysis**

### ***Photosynthetic characteristics***

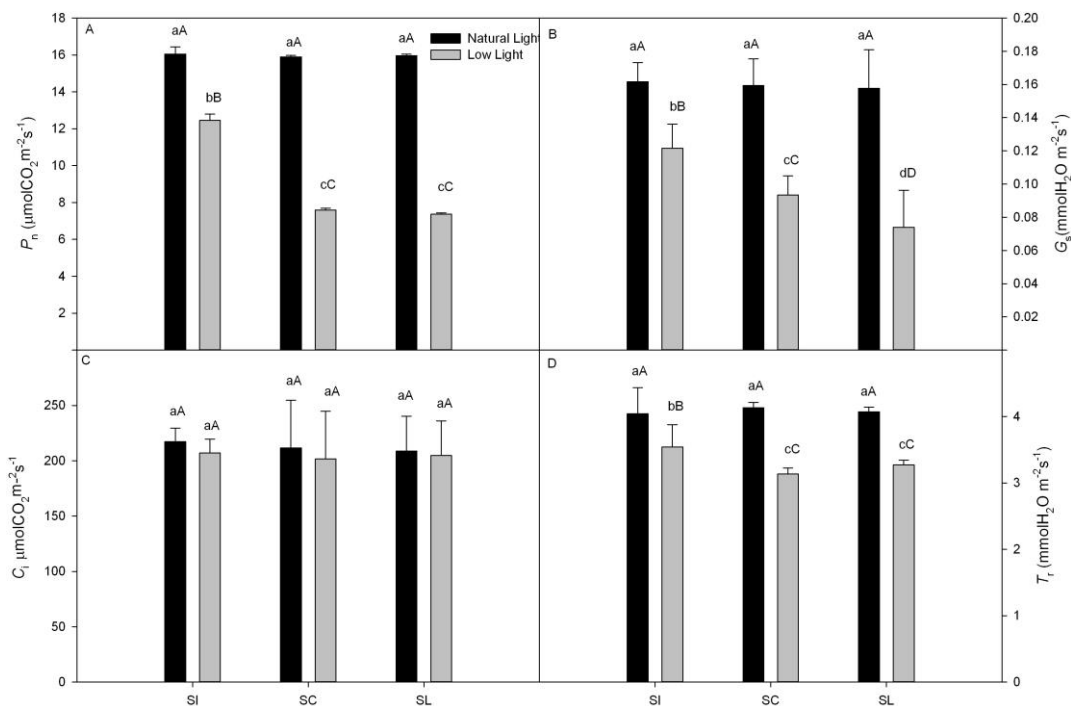
The photosynthetic gas exchange parameters of *Syringa* leaves were significantly affected by low light. In the low light,  $P_n$ ,  $G_s$  and  $T_r$  values of *Syringa* leaves decreased (Fig. 2). The  $P_n$ ,  $G_s$  and  $T_r$  descent range of *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) than *Syringa oblata* Iandl (SI).

### ***Chlorophyll and anthocyanin content***

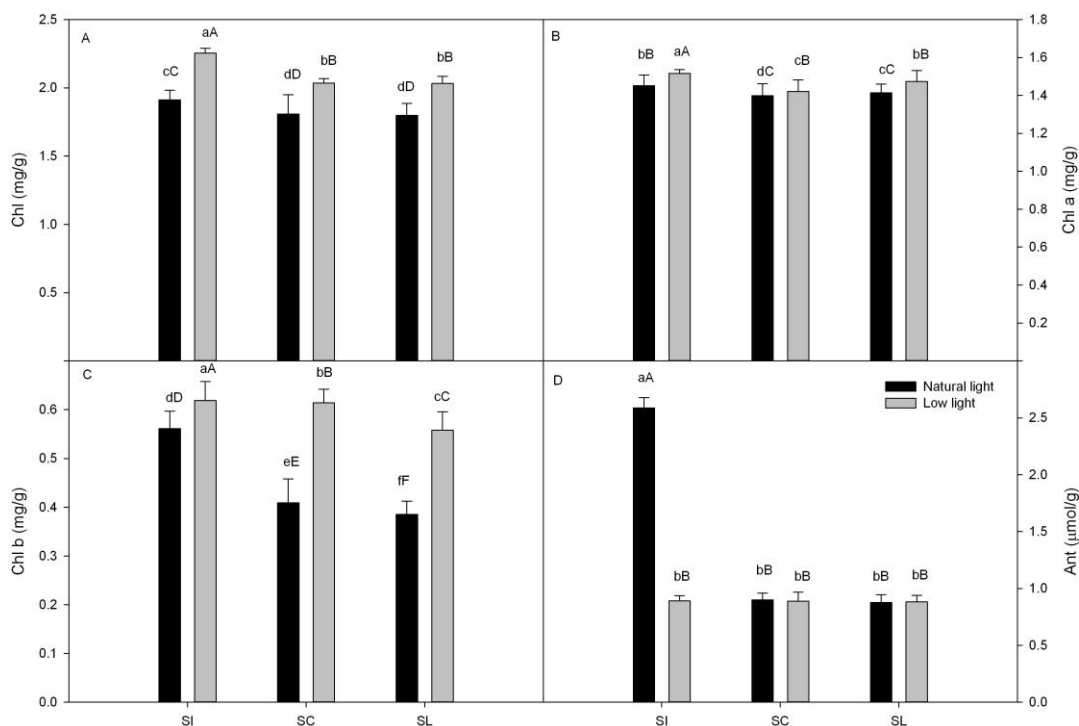
The contents of total Chlorophyll, Chla and Chlb in natural light were significantly lower than that in low light for all the three varieties (Fig. 3A-C). Ant content of leaves in the low light were higher than that in natural light leaves for *Syringa oblata* Iandl (SI). However, Ant content in leaves of *Syringa oblata* Iandl (SI) showed no significant differences among three varieties of *Syringa* in the low light ( $p < 0.05$ ). Ant content in leaves of *Syringa oblata* Iandl (SI) was significantly increased by 65.3% and 66.1% than that of *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) in the natural light, respectively.

### ***Standardized OJIP curves***

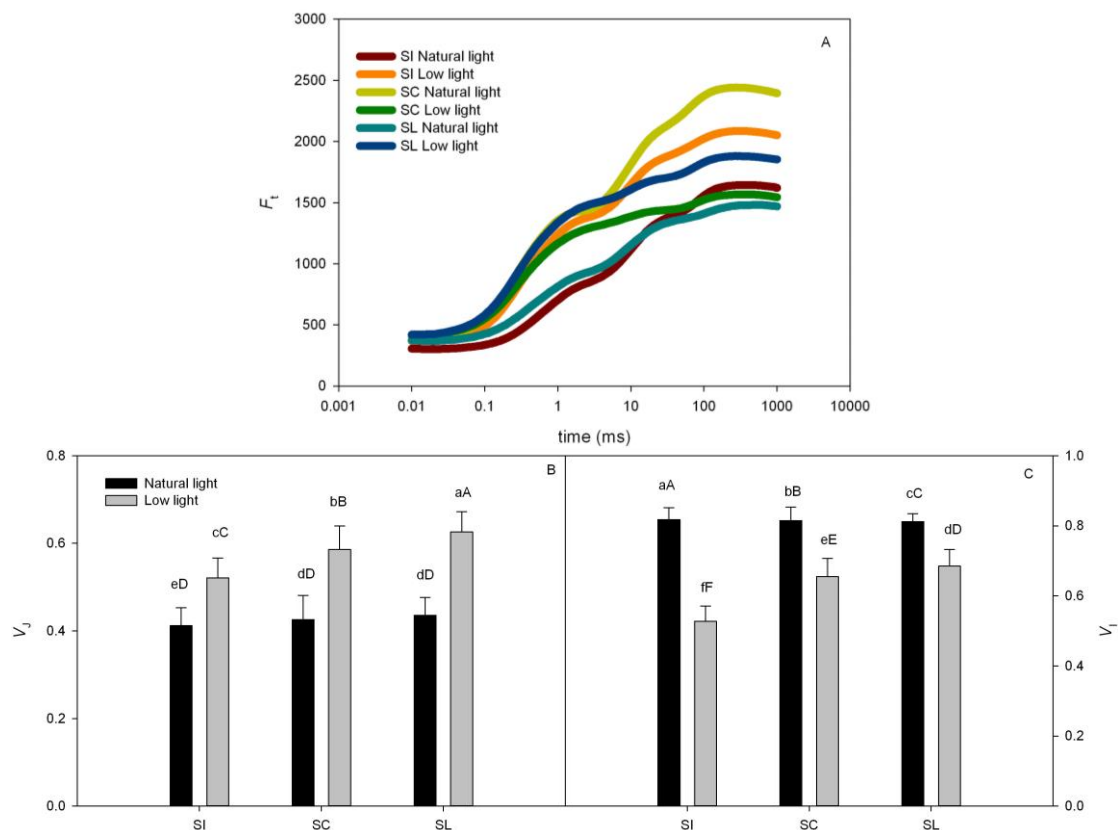
According to this standardization of OJIP curve (Fig. 4A), compared with the natural light, the relative variable fluorescence  $V_i$  of three *Syringa* leaves in low light increased significantly, and the relative variable fluorescence  $V_I$  of point I increased significantly more than that of point J (Fig. 4B-C). The results showed that the  $V_J$  and  $V_I$  of *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) under natural light were significantly higher than those of *Syringa oblata* Iandl (SI) ( $P < 0.05$ ).



**Figure 2.** Photosynthetic characteristics among three varieties of *Syringa*. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* Iandl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh



**Figure 3.** Chlorophyll and anthocyanin content in leaves among three varieties of *Syringa*. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* Iandl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh



**Figure 4.** The rise kinetics of relative variable fluorescence  $V_t = (F_t - F_o)/(F_m - F_o)$  and difference of  $V_j$  and  $V_i$  in leaves of 3 cultivars *Syringa* under different light conditions. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* Iandl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh

### Minimal fluorescence ( $F_o$ ) and maximum fluorescence ( $F_m$ )

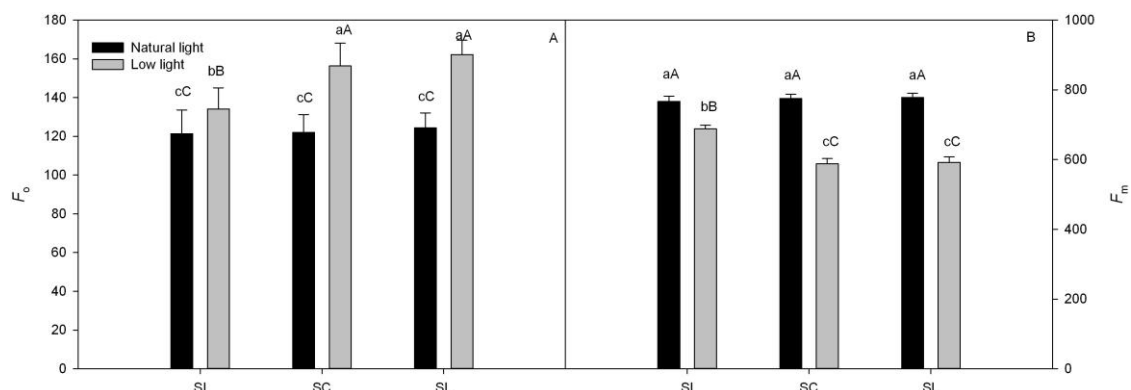
The  $F_o$  of leaves in the natural light were lower than that in the low light leaves for *Syringa oblata* Iandl (SI) significantly ( $P < 0.01$ ), but the  $F_o$  was lower than *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) (Fig. 5A). In *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC),  $F_m$  of the leaves in the low light were also lower than that in the natural light leaves ( $P < 0.01$ ), in the natural light leaves of three *Syringa* at  $F_o$  and  $F_m$  had no significant difference ( $P > 0.05$ ).

### PSII photochemical efficiency

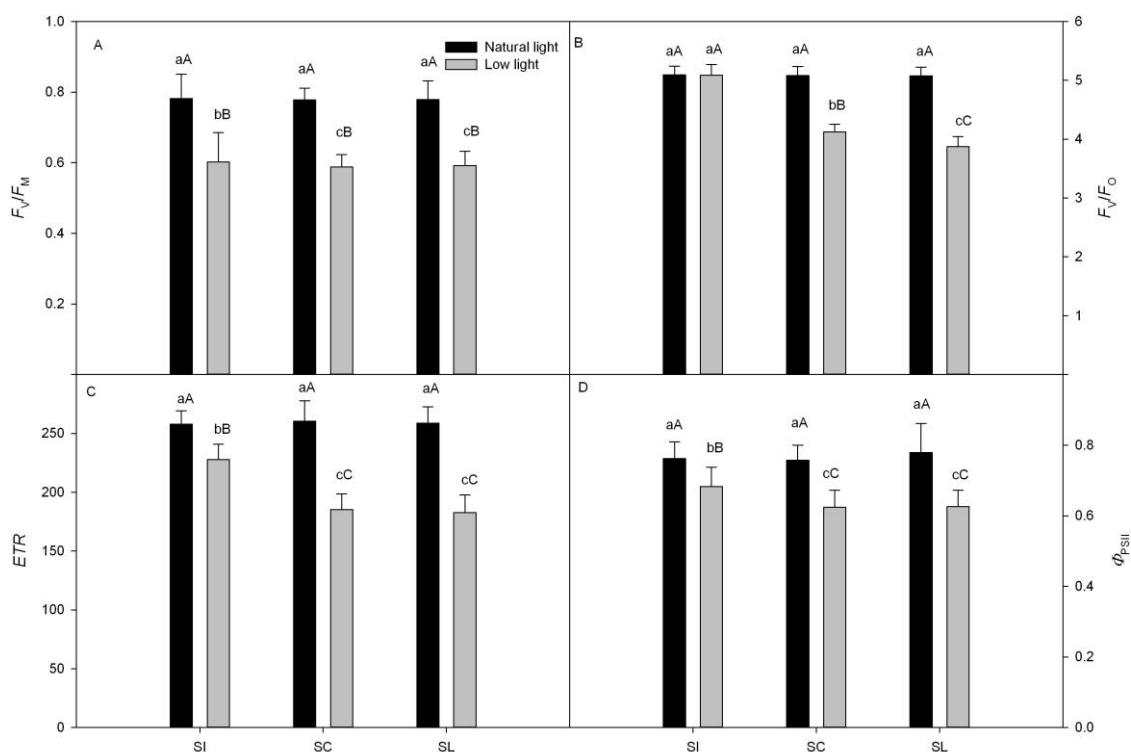
$F_v/F_m$  of leaves in the low light was significantly lower than that in the natural light for the three *Syringa* species.  $F_v/F_o$  of leaves in the low light were lower than the natural light by 18.89% ( $p < 0.01$ ) for *Syringa oblata* var. *affinis* Lingelsh (SL) and 23.74% ( $p < 0.01$ ) for *Syringa chinensis* (SC) (Fig. 6A-B). There were no significant difference in  $F_v/F_o$  ( $p > 0.05$ ) between in the low light and in the natural light leaves of *Syringa oblata* Iandl (SI).

There were no obvious differences in  $ETR$  and  $\Phi_{PSII}$  of leaves in the natural light between the three species. However,  $ETR$  and  $\Phi_{PSII}$  of leaves in the low light were

significantly lower in *Syringa oblata* var. *affinis* Lingelsh (SL) than *Syringa oblata* *landl* (SI) by 18.50% and 12.14%, respectively, and *Syringa chinensis* (SC) by 19.38% and 12.30%, respectively. ( $p > 0.05$ ) (Fig. 6C-D).



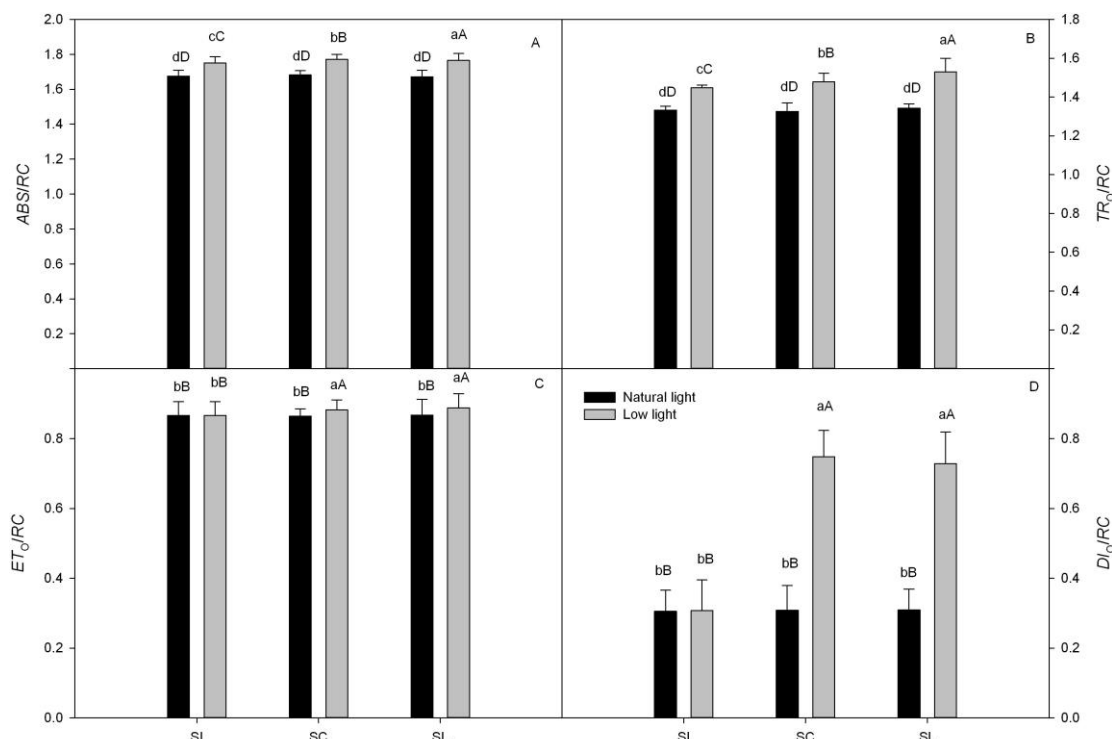
**Figure 5.** Minimal fluorescence ( $F_o$ ) and maximum fluorescence ( $F_m$ ) in leaves of three *Syringa*. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* landl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh



**Figure 6.** PSII photochemical efficiency ( $F_v/F_m$ ), actual photochemical efficiency ( $\Phi_{PSII}$ ), the electron transport rate (ETR) and potential activities ( $F_v/F_o$ ) in leaves of three *Syringa*. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* landl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh

### Specific activity coefficient of PSII reaction center in leaves of *Syringa*

$ABS/RC$ ,  $TR_o/RC$ ,  $ET_o/RC$  and  $DI_o/RC$  had no significant differences in the natural light for the three *Syringa* (Fig. 7A-D). These parameters were significantly higher in the low light than in the natural light ( $p < 0.01$ ) for *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC). The values of  $DI_o/RC$  and  $ET_o/RC$  of the leaves in the low light were no significant differences between in the natural light and in the low light for *Syringa oblata* Iandl (SI) ( $p < 0.05$ ).



**Figure 7.** The values of  $ABS/RC$ ,  $TR_o/RC$ ,  $ET_o/RC$  and  $DI_o/RC$  leaves. Data in the figure are mean  $\pm$  SD, values followed by different small letters mean significant difference ( $p < 0.05$ ), values followed by different capital letters mean very significant difference ( $p < 0.01$ ). SI: *Syringa oblata* Iandl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh

### PSII energy allocation pathways in leaves of *Syringa*

The  $\Phi_{NF}$  in the low light was higher than that in the natural light for all the three *Syringa*, but the  $\Phi_{NPQ}$  showed opposite trends (Fig. 8). The  $\Phi_{PSII}$  in the low light were much lower than the natural light leaves for *Syringa oblata* var. *affinis* Lingelsh (SL). The  $\Phi_{PSII}$  in the low light of *Syringa oblata* Iandl (SI) was higher than the *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC). The  $\Phi_{NF}$  values were listed in a decreasing order: *Syringa oblata* var. *affinis* Lingelsh (SL) > *Syringa chinensis* (SC) > *Syringa oblata* Iandl (SI).

### Chl a fluorescence kinetics the selected JIP-test parameters

According the JIP-test parameters, we found that  $PI_{ABS}$ ,  $F_j$ ,  $F_1$ ,  $F_m$ ,  $\Psi_o$  and  $\phi E_o$  in the leaves of three *Syringa* were significantly lower than under natural light (Fig. 9). All parameters showed a declining trend. However, the  $\phi D_o$  of *Syringa oblata* var. *affinis*

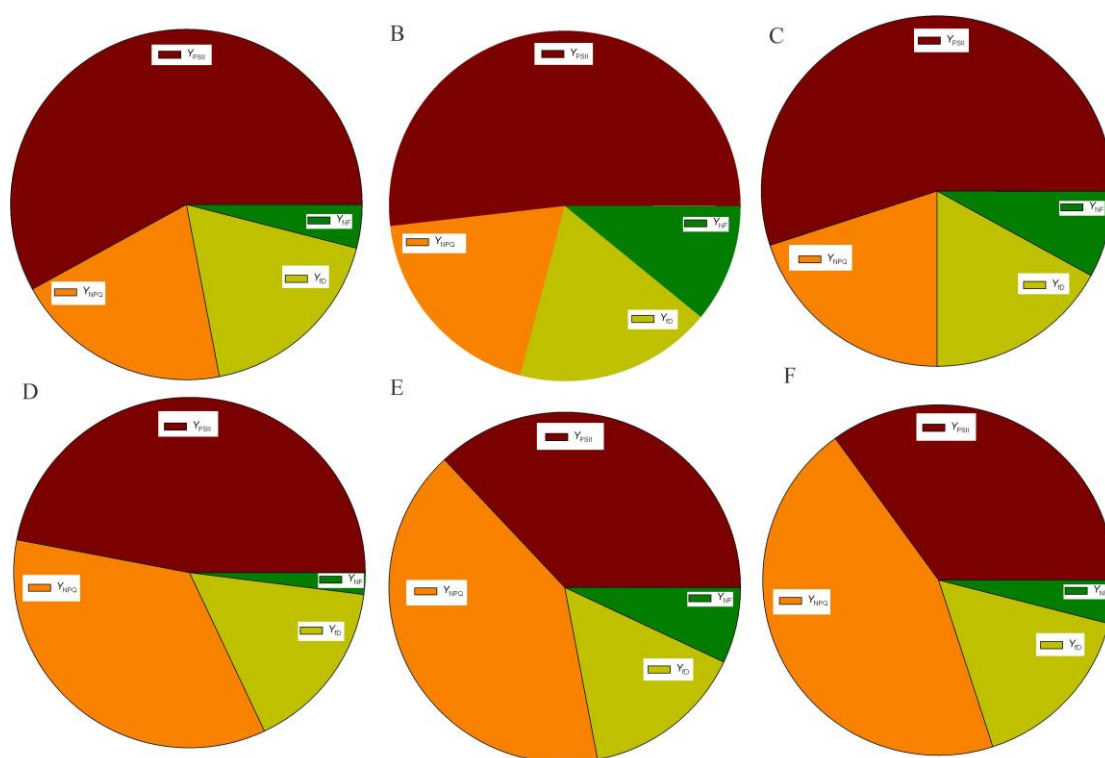


*Lingelsh* (SL) and *Syringa chinensis* (SC) were higher than *Syringa oblata* Iandl (SI) under the low light.

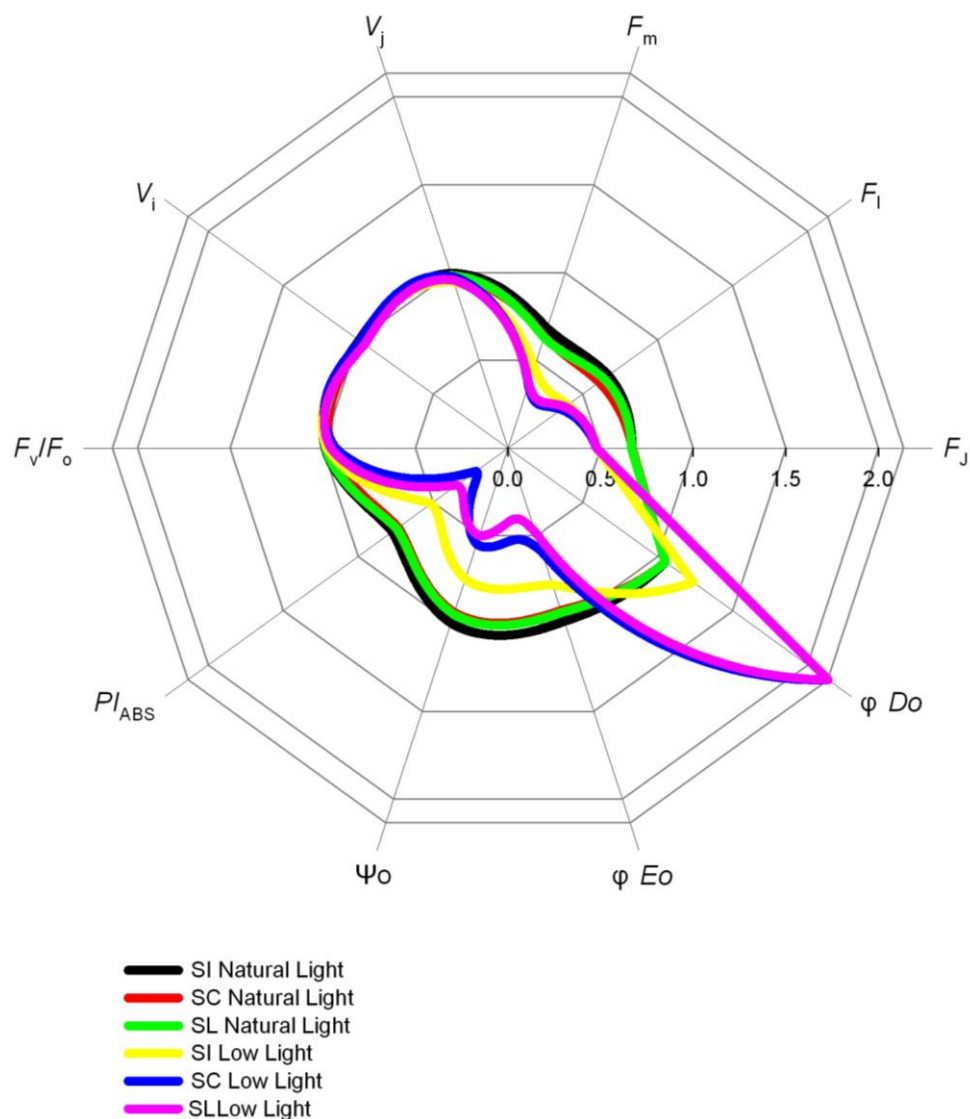
## Discussion

In the present study, the Chl, Chla and Chlb of leaves in the natural light were lower than in the low light for all the three cultivars. The contents of Chl, Chla and Chlb in the low light of *Syringa oblata* var. *affinis* *Lingelsh* (SL) and *Syringa chinensis* (SC) were significantly lower than that of *Syringa oblata* Iandl (SI). It indicates a low efficiency of light absorption and utilization for the low light due to low contents of the photosynthetic pigments. Anthocyanins have the potential roles in relieving damage of excessive light energy to photosynthetic apparatus. In this study, we found the high content of anthocyanins in the low light may be a protection mechanism for the leaves.

In this experiment, under the low light,  $P_n$ ,  $G_s$  and  $T_r$  in leaves of *Syringa* decreased. The stomatal limitation of *Syringa* leaves was significantly improved by the low light. This indicated that the low light impacts the photosynthetic mechanism of *Syringa* leaves, which is related to the reduction of  $CO_2$  utilization capacity, even when the stomatal conductance is reduced. In a word, inoculation with anthocyanins can improve photosynthetic capacity by increasing the stomatal opening and tolerance of photosynthetic apparatus to the low light and other non-stomatal factors. According to Farquhar et al. (1982), it can be concluded that the reduction of photosynthetic capacity of *Syringa* leaves caused by the low light is due to the limitation of both stomatal and non-stomatal factors.



**Figure 8.** PSII energy allocation pathways in natural light leaves of *Syringa oblata* Iandl (A), *Syringa chinensis* (B) and *Syringa oblata* var. *affinis* *Lingelsh* (C) and in low light leaves of *Syringa oblata* Iandl (D), *Syringa chinensis* (E) and *Syringa oblata* var. *affinis* *Lingelsh* (F)



**Figure 9.** Radar-plot of parameters derived from the JIP-Test of three *Syringa*. SI: *Syringa oblata* Iandl; SC: *Syringa chinensis*; SL: *Syringa oblata* var. *affinis* Lingelsh

Among the leading functional hypotheses for the presence of anthocyanins in leaves is that of photoprotection of chloroplasts; under saturated light, anthocyanins potentially mitigate photoinhibitory and photo-oxidative damage by absorbing a proportion of the photons surplus to the requirements of the light reactions of photosynthesis (Kevin et al., 2011). The chlorophyll in plant leaves can absorb light energy, so does the Ant (Jiang et al., 2005). In addition, coloration of variety coleus plants major impact of the interaction of Chl and Ant contents (Zhang et al., 2010). In present study, the content of Ant in the low light leaves of *Syringa oblata* Iandl (SI) was higher than *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC). However, this effect of Ant existence on photosynthetic pigments was expected in view of earlier studies that showed the role of filtration (Chalker-Scott et al., 1999), attenuation (Gould, 2004) and reflection light (Lee et al., 1979). Anthocyanins were synthesized to alleviate oxidative stress resulting from low water potentials, either through acting as an antioxidant or through light-attenuation. As a result, the absorbing light capacity of the low light

leaves in *Syringa oblata Iandl* (SI) was lower than *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC). In other words, reduced the proportion of PS II absorb the light energy in the low light leaves of *Syringa oblata Iandl* (SI) due to Ant could avoid potential hazard by the excess light energy of PSII. By contrast, those parameters were remarkably similar between red and green leaves. Red leaves are evidently better equipped to deal with surplus incident photons, elevating their photochemical performance to that of green leaves (Kevin et al., 2011).

The relative fluorescence intensity  $F_t$  of each point on the OJIP curve of *Syringa oblata Iandl* (SI) leaves is significantly lower than that of *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC), which may be due to the fact that there are a lot of anthocyanins in SI leaves, which attenuates part of the action light intensity. However, under low light, the synthesis of anthocyanin in *Syringa oblata Iandl* (SI) leaves was inhibited, which led to the increase of the relative fluorescence intensity  $F_t$  of each point on the OJIP curve, which further indicated that the existence of anthocyanin could reduce the fluorescence quenching in plant leaves to a certain extent, which may suggest that anthocyanin has a certain defense mechanism of light damage (Chen et al., 2017). In our experiment, the increase of  $V_I$  in three *Syringa* leaves under low light intensity was significantly larger than that in  $V_J$ , that is to say, the main reason for the obstruction of electron transfer on the electron acceptor side of PS II in three kinds of *Syringa* leaves was that the low light intensity led to the increase of  $V_J$  and  $V_I$ , and the increase of  $V_J$  and  $V_I$  could reflect the accumulation of  $Q_A^-$ . It is related to the ability reduction of  $Q_B$  and PQ to accept electronic, and the reduction of PQ library capacity is the main speed limit step (Zhang et al., 2012; Tariq et al., 2017).

Correlation analysis showed a high correlation between pigment content and chlorophyll fluorescence parameters in low light leaves of the three *Syringa* species (Table 1). The *Syringa oblata Iandl* (SI) due to abound with Ant that attenuated energy which used for photosynthesis organization. Therefore, the  $F_o$  and  $F_m$  of the *Syringa oblata Iandl* (SI) was lower than that of the *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC) which had lower Ant pigment. Scilicet, no matter the reaction center was all opened or closed, the yield for Chlorophyll fluorescence were all relatively low. It indicates that light absorption of the two *Syringa* was obviously decreased due to the existence of Ant. In this study, the experiment was conducted in late August in the autumn of Harbin, with the conditions of declining temperature and high light intensity. The combined effects of low temperature and high light often led to leaf photoinhibition or even light damage (Feng et al., 2009; Zhang et al., 2011a). The experimental results showed that all the values of  $F_v/F_m$ ,  $F_v/F_o$ ,  $ETR$  and  $\Phi_{PSII}$  of leaves in the low light were all higher in *Syringa oblata Iandl* (SI) than in the *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC). It indicates that the protective effects of the Ant in the *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC) were weaker. The reduction of the PSII reaction center activity and the open level of reaction center blocked the electron transport of leaves and inhibited primary reaction of photosynthesis, all the factors led to the reduction of light quantum reaching PSII reaction center (Zhang et al., 2012; Tariq et al., 2017; Liu et al., 2019). So the proportion of light energy for photochemical reaction was reduced. However, the activity of PSII reaction center was inhibited significantly for the leaves with higher Ant content.

**Table 1.** Correlation coefficients between pigment content and chlorophyll fluorescence parameters in low light leaves of three *Syringa*

	<b>Chl</b>	<b>Chla</b>	<b>Chlb</b>	<b>Ant</b>
<b>F<sub>o</sub></b>	0.99**	0.99**	0.98**	-0.97**
<b>F<sub>m</sub></b>	0.97**	0.98**	0.96**	-0.95*
<b>F<sub>v</sub>/F<sub>m</sub></b>	-0.85*	-0.84*	-0.90*	0.89*
<b>F<sub>v</sub>/F<sub>o</sub></b>	-0.79	-0.76	-0.85	0.83
<b>Φ<sub>PSII</sub></b>	-0.99**	-0.99**	-0.99**	0.99**
<b>ETR</b>	-0.99**	-0.99**	-0.98**	0.98**
<b>ABS/RC</b>	0.99**	0.99**	0.99**	-0.99**
<b>TR<sub>o</sub>/RC</b>	0.99**	0.99**	0.99**	-0.99**
<b>ET<sub>o</sub>/RC</b>	0.99**	0.98**	0.99**	-0.99**
<b>DI<sub>o</sub>/RC</b>	0.99**	0.99**	0.98**	-0.97**

\*, \*\* indicate statistical significance at a = 0.05 or a = 0.01, respectively

Variation parameters of the reaction center unit specific activity were not only attenuated light absorption and utilization, but also reflect the important indicators of the number of the active reaction center and the activity of the reaction center under stress (Havaux and Tardy, et al., 1997; Strasser et al., 1995; Zhang et al., 2011b; Li et al., 2019). In the present study, the *ABS/RC*, *TR<sub>o</sub>/RC*, *ET<sub>o</sub>/RC* and *DI<sub>o</sub>/RC* in *Syringa oblata Iandl* (SI), which were rich in Ant, were both striking lower than the low light leaves of *Syringa oblata var. affinis Lingelsh*. It implies that the number of reaction center in the low light leaves of the *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC) was decreased under low temperature and high light stress in the autumn. This force had a surplus of the active reaction center rising on the function, which showed an augmentation at the parameter of the reaction center unit specific activity. However, the low light leaves with a high content of Ant led to reduction of light absorption, which potentially reduced the high light damage to PSII reaction center.

Based on the theory of Luke Hendrickson, excitation energy captured by leaf pigments is distributed to the following four parts:  $\Phi_{NF}$ ,  $\Phi_{PSII}$ ,  $\Phi_{NPQ}$ ,  $\Phi_{f,D}$ . It was an important part for researching the photosynthesis of plants that could research the trace of leaves absorption of light eventually. We have earlier reported whereabouts of light energy was more directly to actual photochemical efficiency ( $\Phi_{PSII}$ ) and Non-photochemical quenching (NPQ) to represent (Genty et al., 1898; Bilger et al., 1995; Hendrickson et al., 2004, 2005; Cai et al., 2019;), however, the increase in NPQ value was just due to an establishment of trans-thylakoid pH gradient and xanthophyll cycle in the higher plant (Lavaud and Kroth, 2006; Yin et al., 2019; Yang et al., 2020). But NPQ could not represent all processes of non- photochemical quenching, for this reason we need to redefine the photosynthesis of excitation energy distribution. Excitation energy are distributed into four parts ( $\Phi_{NF}$ ,  $\Phi_{PSII}$ ,  $\Phi_{NPQ}$  and  $\Phi_{f,D}$ ) based on the theory of Luke Hendrickson (Hendrickson et al., 2005; Guo et al., 2017). In the present study, light absorption of PSII reaction center in the low light leaves of *Syringa* due to the content of Ant has distribution again.  $\Phi_{PSII}$  values of the low light leaves of *Syringa oblata Iandl* (SI) was higher than that of *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa chinensis* (SC), however their  $\Phi_{NF}$  values were significantly lower than *Syringa oblata var. affinis Lingelsh* (SL) and *Syringa*

*chinensis* (SC). It implies that PSII reaction center in the low light leaves of *Syringa oblata* Iandl (SI), *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) could maintain the normal transmission of electron and reduce the number of leaves deactivation reaction center under the low temperature and high light stress in the autumn. The low light leaves with a low content of Ant absorbed more light energy, this led to light excess and light damage to PSII reaction center in the autumn. In contrast, the deactivation reaction center had the capability of the non-radiant energy dissipation which was an important role for the restitution of the reaction center of PSII and maintenance of the function of active reaction center (Lee et al., 2011; Yin et al., 2019; Yang et al., 2020). Therefore, the low light leaves of the *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) maintained normal physiologic function of photosystems through reducing the activity and the number of the PSII reaction center. Where difference with the *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC), the low light leaves of the *Syringa oblata* Iandl (SI) due to the existence of Ant reached a balance between light energy absorption and utilization under the low temperature and high light in the autumn, which could ensure the normal physiologic function of the photosynthesis mechanism in the low light leaves.

## Conclusions

The existence of the Ant was testified that could have obvious effect on the characteristics of chlorophyll fluorescence and distribution parameter of the light in the low light leaves of the *Syringa* under the low temperature and high light stress in the autumn. The photochemical activity of the low light leaves in the *Syringa oblata* Iandl (SI) which were rich in the Ant were much higher than the *Syringa oblata* var. *affinis* Lingelsh (SL) and *Syringa chinensis* (SC) due to the lower content of the Ant. The Ant in the low light leaves can maintain the activity and quantity of PSII reaction center under low temperature and high light stress in the autumn. It can also keep photosynthetic physiological function in the low light leaves through changing the light distribution parameter of PSII reaction center that alleviate the photoinhibition of the low light leaves in the *Syringa oblata* Iandl (SI). Our results provide the basis for different light utilization schemes for *Syringa*. In order to further explain the decline of photosynthetic mechanism capacity and especially chlorophyll fluorescence, induced by low light, but this needs further study.

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