Leaf Coloration and Photosynthetic Characteristics of Hybrids between *Forsythia ‘Courtaneur’* and *Forsythia koreana* ‘Suwon Gold’

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**Abstract.** Yellow-leafed cultivars usually do not grow as vigorous as their green-leafed counterparts, which affect their use in landscapes. To breed *Forsythia* cultivars with both yellow leaves and vigorous growth, crosses between *F. ‘Courtaneur’* and *Forsythia koreana* ‘Suwon Gold’ were conducted, and 52 F\(_1\) hybrid progenies with different leaf colors (green, chartreuse, and yellow) were obtained. The progenies were categorized into three groups (Yellow Group (YG), Chartreuse Group (CG), and Green Group (GG)) based on leaf colors. The growth index (GI) and the number of branches and leaves of YG progenies were significantly lower at 2%, 35%, and 34% of GG progenies. As the leaves changed from green to chartreuse and to yellow, chlorophyll content, leaf thickness, and chlorophyll fluorescence parameters decreased and the chloroplast structures were disintegrated gradually, which influenced the leaf photosynthetic activity and led to weak growth. Compared with yellow-leafed progenies, the leaf chlorophyll content and leaf thickness of chartreuse-leafed progenies were significantly higher at 71% and 9%. The chloroplast structure of stroma lamella of chartreuse-leafed progenies was relatively intact. Carboxylation efficiency (CE), photochemical efficiency of PS II (F\(_{v}/F\_m\)), and the number of branches and leaves of GG progenies were significantly higher than YG progenies; however, they have no significant difference with CG progenies. The results were promising for breeding new forsythia cultivars from moderate growth and chartreuse leaves.

Yellow-leafed plants, with leaves showing different shades of yellow, are widely used in landscapes (Yu and Zhang, 2000). Mutations in both nuclear and organelle genomes reportedly cause leaf-leafed variation (Gao et al., 2016; Liu et al., 2016; Moseyko et al., 2002; Xiao et al., 1995). There are significant differences between yellow-leafed plants and green-leafed ones in terms of pigment contents, photosynthesis, and leaf structure (Hu et al., 2007; Zhang et al., 2015). Total leaf chlorophyll content and the ratio of chlorophyll to carotenoid content in yellow-leafed plants are generally lower than that of their green-leafed counterparts (Hu et al., 2007). Photosynthetic apparent quantum yield (AQY) of yellow-leafed plants is lower than that of green-leafed ones in *Eupatorium makinai* (Funayama et al., 1997). The net photosynthetic rate of yellow-leafed *Sophora japonica* var. *golden* is lower than that of the green-leafed species *S. japonica* (Liu et al., 2003). There is a significant difference in chloroplast structure between yellow-leafed and green-leafed plants, and the decrease in the number of granum and granum lamellae results in the reduction of chlorophyll content and the incomplete development of photosynthetic system, which then results in yellow leaves with lower photosynthetic capacity and weak growth in *Brassica napus* and *Ulmus pumila ‘Jinye’* (Xiao et al., 2013; Zhu et al., 2014).

*Forsythia koreana* ‘Suwon Gold’ is a beautiful cultivar with bright yellow leaves on the outside of the canopy throughout the growing season. Compared with green-leafed cultivars, ‘Suwon Gold’ is less vigorous, and leaf scorch often occurs under high light intensity during summer. To breed forsythia cultivars with both bright yellow leaves and vigorous growth, interspecific crosses between *F. ‘Courtaneur’* (female parent with green leaves) and ‘Suwon Gold’ (male parent) were carried out, and F\(_1\) progenies with different leaf colors were obtained in the study. The growth, leaf pigment contents, photosynthetic parameters, leaf structure, and chloroplast structure were investigated to lay a foundation for understanding the formation of yellow leaves in *Forsythia*.

**Materials and Methods**

**Plant materials.** The parent plants used in hybridization were 3 years old and were planted in the nursery of National Engineering Research Center for Floriculture (NERCF) (40°02′N, 115°50′E) in Beijing, China. Pollinations were performed in Apr. 2013. The dehiscent and undersized buds of ‘Courtaneur’ were removed, whereas the flowers which could dehisce in 1 d were emasculated and pollinated at 11:00 AM -to noon with freshly collected pollens of ‘Suwon Gold’. The pollinated flowers were then bagged and tagged immediately. A total of 351 hybrid seeds were obtained on ‘Courtaneur’ plants in October. The seeds were sowed in 50-cell plug trays (the top and bottom diameter is 50 and 22 mm, respectively, and the depth is 50 mm) in a greenhouse on the campus of Beijing Forestry University on 15 Nov. 2013. Fifty-two seedlings were obtained and then planted in the nursery of NERCF on 18 May 2014.

**Morphological characteristics.** The plant height, crown widths, and the number of branches and leaves of hybrid progenies were measured every 15 d from 20 Apr. to 18 Oct. 2014. Growth index was calculated using the following equation: GI (m²) = π(w/2)\(^2\) × h; where: the average two plant widths, one measured at the widest point and the other one perpendicular to the first; h: the plant height; Debalin et al., 2015). The colors of fully expanded leaves of the third to fourth nodes from the top of current growth of every progeny were confirmed using the fifth edition of Royal Horticultural Society Color Chart.

**Leaf pigment content.** Five plants randomly chosen from parent and progeny
groups were used to measure leaf pigment contents. Mature leaves of the third to fourth nodes from the top of shoots under full sun were collected and frozen in liquid nitrogen and then preserved at −80 °C. The contents of chlorophyll a (Chl a), chlorophyll b (Chl b), and carotenoid were extracted and measured with a BioMate 3S ultraviolet-visible spectrophotometer (Thermo Fisher Scientific, Shanghai, China) following Wang’s (2006) protocol.

Microstructure of leaf and ultrastructure of leaf chloroplast. Mature leaves selected from the third fully expanded leaf were collected from the parent plants, three groups of progenies were cut into pieces of 4 ± 4 mm, and then dehydrated pieces were obtained. To observe the microstructure of leaf and ultrastructure of leaf chloroplast, semithin sections, thin sections, and ultrathin sections were made. The methods for obtaining semithin sections and ultrathin sections were in accordance with the method of Zhang et al. (2011). The dehydrated samples were embedded in epoxy resin and were sliced with a BioMate 3S ultraviolet-visible spectrophotometer (Thermo Fisher Scientific, Shanghai, China) following Wang’s (2006) protocol.

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Chlorophyll fluorescence parameter measurements. Minimal fluorescence (F₀) and maximum fluorescence (Fₘ) of the leaves (same as those selected for photosynthetic parameters measurement) were measured using PAM-2500 photosynthesis analyzer (MINI-PAM, Walz, Effeltrich, Germany). The variable fluorescence (Fᵥ), Fₘ/F₀, and potential activity of PS II (Fₐ/Fₘ) were calculated by applying the formula of F₀ = Fₘ – Fₚ (Olaf and Snel, 1990). To determine the dark-adaption time, the fluorescence parameters of ‘Courtaneur’ and ‘Suwon Gold’ were measured after 20 and 30 min in the darkness, respectively, and the data of Fₚ and Fₘ both have no significant differences. So, 20 min dark-adaption was used in our research.

Data analysis. The design was a one factor (leaf color) complete randomized one with three (photosynthetic characteristics) or five (growth and leaf characteristics) replications. The experiment was conducted in July and Aug. 2014. The data were analyzed by Duncan analysis of variance using SPSS 18.0 (IBM, Armonk, NY).

Results

Morphological traits of hybrid progenies. The leaf color of 52 progenies ranged from yellow to green in the hybrid population (Fig. 1). Based on leaf colors, the progenies were divided into YG (9 plants), CG (25 plants), and GG (18 plants). The Royal Horticultural Society Color Chart color codes for YG, CG, and GG plants were Yellow Green Group 151 to 153, Yellow Green Group 144 to N144, and GG 137 to 143, respectively.

Growth of hybrid progenies. There were significant differences in growth between YG and GG (Table 1). The GI and the number of branches and leaves of YG progenies were 2%, 35%, and 34% of GG progenies at the end of the growth period, respectively. The growth of CG progenies was between that of GG and YG, being 23%, 71%, and 66% of GG progenies.

Leaf pigment contents of progeny groups. In F₁ population, the contents of Chl a, Chl b, total chlorophyll, and carotenoid gradually decreased as the leaves changed from green to yellow, and there were significant differences among the three groups. In general, the pigment contents of YG and CG progenies were close to ‘Suwon Gold’, whereas the pigment contents of GG progenies were close to ‘Courtaneur’. The ratio of Chl a/b in YG progenies was greater than that in GG (Table 2).

Microstructure of leaf and ultrastructure of chloroplast. The palisade tissue (PT) of YG progenies has one layer of cells (Fig. 2A), whereas the PT of CG (Fig. 2B) and GG progenies (Fig. 2C) has two layers of cells. The PT of F. koreana ‘Suwon Gold’ (Fig. 2D) has one or two layers of cells. The PT of F. ‘Courtaneur’ (Fig. 2E) has more than two layers of cells. The chloroplasts are mainly distributed in spongy tissue (ST) and PT. Table 3 shows that the thickness of ST has not been significantly different between GG and CG, CG, and YG, whereas the thickness of PT and CTR has been significantly different among the three group.

![Fig. 1. Different leaf shapes and colors in F. ‘Courtaneur’ × F. koreana ‘Suwon Gold’ hybrid population (examined on 22 July 2014; bar = 3 cm).](image-url)
progenies. As leaf color changes from green to yellow among F1 progenies, PT, ST, and CTR decrease gradually, and the leaves become thinner mainly because of the changes in the thickness of PT. Meanwhile, the thickness of upper epidermis (U) has no significant differences among progenies, whereas the thickness of the lower epidermis of CG is significantly higher than that of YG and GG (Table 3).

Most chloroplasts disintegrate in the yellow leaves of *F. koreana* ‘Suwon Gold’ (Fig. 3A), whereas the green leaves of *F. koreana* ‘Suwon Gold’ have normal chloroplasts (Fig. 3B). There is no visible structure of grana lamellae (G) in the yellow leaves of YG progenies (Fig. 3C and D). Grana lamellae may have disintegrated to small vesicle structures filled in chloroplasts (Fig. 3C). There are few or no visible starch granules (S), but the OG increased (Fig. 3D). The

### Table 1. The annual changes of growth index (GI), branch number, and total leaf number of three groups of progenies in *F. ‘Courtaneur’ × F. koreana* ‘Suwon Gold’ hybrid population.

| Phenotype       | No. of hybrid progenies | GI (m³) | No. of branches | No. of leaves |
|-----------------|-------------------------|---------|-----------------|--------------|
| Green Group     | 18                      | 124.4±3 ± 8.7 a | 3.4± 2.6 a     | 200.4± 124.0 a |
| Chartreuse Group| 25                      | 28.1±3 ± 7.6 b | 2.4± 2.3 ab    | 132.0± 94.2 ab |
| Yellow Group    | 9                       | 2.7±3 ± 0.4 c  | 1.2± 1.0 b     | 67.8± 51.7 b  |

zGI was calculated using equation: GI (m³) = π(w/2)² × h.

yMeans ± SE followed by the same letter in the same column are not significantly different at the 0.05 level based on Duncan’s test.

### Table 2. The contents of photosynthetic pigments of three groups of progenies in *F. ‘Courtaneur’ × F. koreana* ‘Suwon Gold’ hybrid population, in comparison with parent plants.

| Group                      | Chl a (mg·g⁻¹) | Chl b (mg·g⁻¹) | Chl (mg·g⁻¹) | Chl a/b | Carotenoid (mg·g⁻¹) |
|----------------------------|----------------|----------------|--------------|---------|---------------------|
| Forsythia Courtaneur (♀)  | 0.9± 0.3 b     | 0.3± 0.1 b     | 1.2± 0.4 b   | 3.5± 0.2 bc | 0.3± 0.1 b         |
| Green Group                | 1.4± 0.3 a     | 0.4± 0.1 a     | 1.9± 0.4 a   | 3.4± 0.1 c  | 0.5± 0.1 a         |
| Chartreuse Group           | 0.6± 0.2 c     | 0.1± 0.0 c     | 0.7± 0.2 c   | 7.0± 1.0 a   | 0.2± 0.1 c         |
| Yellow Group               | 0.2± 0.1 d     | 0.1± 0.0 c     | 0.2± 0.1 d   | 4.7± 2.5 b   | 0.1± 0.0 d         |
| F. koreana Suwon Gold (♀) | 0.5± 0.2 c     | 0.1± 0.0 c     | 0.5± 0.2 c   | 7.9± 0.9 a   | 0.1± 0.0 cd        |

*Total chlorophyll content = Chl a + Chl b.*

yMeans ± SE followed by the same letter in the same column are not significantly different at the 0.05 level based on Duncan’s test.

### Table 3. The leaf anatomical structure of the three groups of progenies in *F. ‘Courtaneur’ × F. koreana* ‘Suwon Gold’ hybrid population, in comparison with parent plants.

| Group                      | Upper epidermis thickness (µm) | Palisade thickness (µm) | Spongy thickness (µm) | Lower epidermis thickness (µm) | Leaf thickness (µm) | CTR (%) |
|----------------------------|--------------------------------|-------------------------|----------------------|-------------------------------|---------------------|---------|
| Courtaneur (♀)             | 22.4± 3.1 a                    | 170.6± 31.4 a           | 189.0± 27.5 a        | 17.6± 3.1 a                   | 336.5± 58.1 a       | 0.32± 0.0 a |
| Green Group                | 19.4± 1.9 b                    | 84.7± 10.0 b            | 160.7± 14.5 b        | 15.4± 1.7 b                   | 280.1± 9.7 b        | 0.30± 0.0 a |
| Chartreuse Group           | 18.2± 3.1 b                    | 67.8± 22.8 c            | 148.3± 28.6 bc       | 15.2± 2.9 c                   | 249.5± 44.1 c       | 0.27± 0.1 b |
| Yellow Group               | 19.1± 3.2 b                    | 44.5± 11.2 d            | 146.8± 16.4 c        | 15.9± 2.6 b                   | 226.2± 8.9 d        | 0.20± 0.1 d |
| Suwon Gold (♀)             | 21.0± 3.3 a                    | 60.2± 15.9 c            | 156.5± 25.9 bc       | 15.5± 2.4 b                   | 253.1± 39.3 c       | 0.24± 0.0 c |

zCTR= palisade thickness/leaf thickness.

yMeans ± SE followed by the same letter in the same column are not significantly different at the 0.05 level based on Duncan’s test.
chloroplast structure with visible G in CG progenies (Fig. 3E) is between GG (Fig. 3F and G) and YG progenies (Fig. 3C and D); however, the layers of G are less than those in GG progenies (Fig. 3F and G). Meanwhile, the S are visible or intact and the OG are less than those in YG progenies (Fig. 3C and D).

In green leaves of GG progenies (Fig. 3F and G) and F. ‘Courtaneur’ (Fig. 3H and I), there

![Image](image-url)

**Fig. 3.** The chloroplast ultrastructure of *F. koreana* ‘Suwon Gold’ (A and B), three hybrids of different leaf colors (yellow—C and D; chartreuse—E; green—F and G), and *F. ’Courtaneur’* (H and I). G = grana lamellae; OG = osmiophilic granules; and S = starch granules.

**Table 4.** The photosynthetic parameters of three groups (YG = yellow group; CG = chartreuse group; and GG = green group) of progenies in *F. ’Courtaneur’* (♀) × *F. koreana* ‘Suwon Gold’ (♂) hybrid population, in comparison with parent plants.

| Group       | AQY (mmol·mol⁻¹) | LCP (μmol·m⁻²·s⁻¹) | LSP (μmol·m⁻²·s⁻¹) | $P_{\text{max}}$ (μmol·m⁻²·s⁻¹) | Rd (μmol·m⁻²·s⁻¹) | CE (μmol·m⁻²·s⁻¹) | CCP (μL·L⁻¹) | CSP (mL·L⁻¹) | $C_{\text{max}}$ (μmol·m⁻²·s⁻¹) |
|-------------|------------------|---------------------|---------------------|-------------------------------|-------------------|-------------------|---------------|--------------|---------------------------------|
| Courtaneur  | 26.4 ± 3.1 b      | 63.0 ± 14 b         | 1.2 ± 0.1 b         | 12.6 ± 2.0 b                  | 1.6 ± 0.2 b       | 19.4 ± 2.3 b      | 65.0 ± 0.7 b  | 2.0 ± 0.2 a   | 23.8 ± 0.5 b                     |
| GG          | 51.1 ± 12.8 a     | 56.0 ± 4.5 b        | 1.3 ± 0.1 ab        | 18.9 ± 1.6 a                  | 2.9 ± 1.0 a       | 48.6 ± 9.4 a      | 86.8 ± 19.3 b | 1.6 ± 0.2 bc  | 44.2 ± 8.5 a                     |
| CG          | 30.0 ± 8.6 b      | 48.4 ± 15.2 b       | 1.4 ± 0.1 ab        | 11.7 ± 2.3 b                  | 1.3 ± 0.1 bc      | 36.9 ± 7.8 a      | 67.9 ± 8.1 b  | 1.6 ± 0.1 bc  | 25.6 ± 4.3 b                     |
| YG          | 8.1 ± 2.3 c       | 135.8 ± 13.6 a      | 1.4 ± 0.1 ab        | 2.7 ± 1.2 c                   | 1.1 ± 0.3 bc      | 5.4 ± 3.0 c       | 481.0 ± 323.8 a | 1.9 ± 0.0 ab | 3.6 ± 0.2 c                       |
| Suwon Gold  | 10.2 ± 0.2 c      | 42.8 ± 3.8 b        | 1.5 ± 0.2 a         | 3.1 ± 0.8 c                   | 0.5 ± 0.1 c       | 13.8 ± 0.8 bc     | 70.8 ± 0.9 b  | 1.4 ± 0.1 c   | 3.6 ± 0.2 c                       |

AQY = apparent quantum yield; LCP = light compensation point; LSP = light saturation point; $P_{\text{max}}$ = maximum net photosynthetic rate; Rd = dark respiratory rate; CE = carboxylation efficiency; CCP = carbon dioxide compensation point; CSP = carbon dioxide saturation point; $C_{\text{max}}$ = maximum CO$_2$ concentration.

*Means ± se followed by the same letter in the same column are not significantly different at the 0.05 level based on Duncan’s test.*
are many chloroplasts with normal structure of G, and the G are surrounded by mostly oval-shaped S, and S completely fill the chloroplasts.

Photosynthesis and chlorophyll fluorescence of parents and hybrid progenies. Photosynthetic parameters, including AQY, $P_{\text{max}}$, and $C_{\text{max}}$ of the yellow-leaved ‘Suwon Gold’ and YG progenies were significantly lower than those of the other two hybrid groups and ‘Courtaneur’ (Table 4; Fig. 4). However, there was no significant difference between ‘Suwon Gold’ and YG progenies. There was no difference in CE between ‘Suwon Gold’ and ‘Courtaneur’, GG and CG progenies. However, the CE of CG progenies was significantly higher than that of YG progenies. Among the hybrids, YG progenies had significantly higher LCP, CCP, and lower $P_{\text{max}}$ and $C_{\text{max}}$ than CG and GG progenies. There was no significant difference in CE between ‘Suwon Gold’ and ‘Courtaneur’, GG and CG progenies. However, the CE of CG progenies was significantly higher than that of YG progenies. Among the hybrids, YG progenies had significantly higher LCP, CCP, and lower $P_{\text{max}}$ and $C_{\text{max}}$ than CG and GG progenies. There was no significant

![Net photosynthetic rate ($P_n$)–light response curves and ($P_n$–CO$_2$ response curves of three groups of progenies in F. 'Courtaneur' (♂) × F. koreana 'Suwon Gold' (♀) hybrid population. Symbols represent the mean of replications and error bars represent the least significant difference between the means at $P < 0.05$.](image_url)
difference between YG and GG progenies, but the CO₂ and light energy use efficiency of CG progenies were significantly higher than those of YG progenies.

All the chlorophyll fluorescence parameters (F₀, Fₘ, Fᵥ, Fₐ/Fₘ, and Fₐ/Fₗₐ) of yellow-leafed forsythia were significantly lower than those of the other two groups and ‘Courtaneur’ (Table 5).

**Discussion**

Pigment contents and leaf structure in different leaf color performance. Leaf pigments included chlorophyll and carotenoid. The difference in pigment contents is the main reason for different leaf colors, and the higher chlorophyll content is the reason why normal leaves are green. In our research, the contents of Chl a, Chl b, and total Chl content in ‘Suwon Gold’ and YG progenies were significantly lower than that of the green-leafed forsythia. Among interspecific progenies, carotenoid contents decreased significantly with leaf yellowing, which was similar to the results from the researches on golden U. pumila (Zhu et al., 2014). The ratio of Chl a/b of YG progenies was significantly higher than that of CG progenies, which means that the lack of Chl b is higher than that of Chl a and was similar to the researches on Ligustrum lucidum cv. Aurea (Li, 2005) and Capsicum annuum (Ma et al., 2011). The contents of Chl a and carotenoid of CG progenies were higher than those of yellow-leafed forsythia.

For ‘Suwon Gold’ and YG progenies, the layers of PT were less than that in green leaves, and chloroplasts disintegrated, which may be one reason for yellow leaves. This phenomenon was also found in chartreuse-leafed chrysanthemum mutant (Chang et al., 2008). Meanwhile, the stacked granum lamellae in chloroplasts decreased, which led to the decrease of contents in a variety of pigments, causing the leaves to turn yellow (Zhu et al., 2014).

Pigment contents and photosynthetic capacity. The photosynthetic performance is an important factor affecting plant growth, and the plants with strong photosynthetic capacity can accumulate more photosynthates for growth. It was generally found that the growth of yellow-leafed plants was usually weaker and smaller than the green-leafed plants.

In our research, LCP and LSP of the YG progenies were higher than that of GG progenies, whereas AQY was lower, which was similar to the yellow-leafed mutant of Rosa beggeriana (Wei, 2013). The plants with higher AQY have higher growth capacity (Gao, 2013; Wang, 2010; Zhang et al., 2010), and thus the higher AQY of the GG progenies in our research may be one factor for their strong growth. The parameter AQY of ‘Courtaneur’ and CG progenies had no difference; however, it was significantly higher than ‘Suwon Gold’ and CG progenies. Therefore, breeding new forsythia cultivars with moderate growth and chartreuse leaves is promising. We also found that both CE and CCP of YG progenies were lower than that of green-leafed progenies, which is consistent with the results of Zhuang et al. (2007). The results indicated that the CO₂ and light use efficiency significantly decreased with leaves turning yellow, which resulted in the decrease in photosynthetic capacity, and the Fₘₐₓ and Cₘₐₓ of the yellow-leafed forsythia were less than a third of the values of the other groups. The destruction of chloroplast structure was probably the main reason for the decrease in photosynthesis capacity of YG progenies.

Lack of significant difference between the chartreuse-leafed and green-leafed progenies indicated that their photosynthetic capacity was similar (Zhang et al., 2015) and that was consistent with the results of photosynthesis measurements. We concluded that the incomplete development of PS II caused the decrease in photochemical efficiency and potential activity and ultimately decreased the P₇₀₀ of yellow-leafed forsythia. The CG progenies obtained in our research have more normal chloroplasts, and their photosynthetic capacity and growth potential were both significantly higher than those of the yellow-leafed forsythia, which will be important materials for breeding forsythia cultivars with moderate growth and chartreuse leaves.

From the differences in both photosynthetic pigment contents and leaf structure, we concluded that the decrease in photosynthetic pigments content in yellow-leafed forsythia, especially serious deficiencies of chl b, resulted in a significant decrease in light energy absorption and growth. The CTR and chloroplast structure of yellow leaves appeared visibly different from the green leaves, which was consistent with findings in leaf color mutants of B. napus (Dong et al., 2000). Decrease in chloroplasts and disintegration of chloroplast granum lamellae affected light energy absorption of yellow-leafed forsythia and resulted in a decrease in the AQY and CE. This decrease contributed to the decrease in photosynthetic ability, which explained why the growth of yellow-leafed forsythia ‘Suwon Gold’ was significantly lower than that of green-leafed forsythia ‘Courtaneur’. In our experiment, the contents of Chl a, carotenoid, Chl a/b, and CTR of CG progenies were higher than that of YG progenies. Previous studies showed that only Chl a, the center pigment, had the ability to convert light energy into chemical energy and then into chemical energy (Zhang et al., 2012). Higher CTR or more developed PT is correlated to a stronger photosynthetic ability (Jiang et al., 2012), which explained why chartreuse forsythia had higher photosynthetic ability.

Photosynthesis is closely related to plant organic matter accumulation, which will directly affect the growth of plants. Light reaction (PS I and PS II) occurs on thylakoid membrane of chloroplast. In this study, fluorescence parameters Fₐ/Fₘ and of yellow-leafed forsythia were significantly lower than those of the other two groups and ‘Courtaneur’. Under stressed conditions, the value of Fₐ/Fₘ will decrease rapidly (Woo et al., 2008). In terms of YG and ‘Suwon Gold’, the data suggest that natural light intensity might cause light stress. This study also found that the chloroplast structure of yellow-leafed forsythia is abnormal with less thylakoid membrane and high Chl a/b, which could result in lower light capture capability (Zhou et al., 1999). Therefore, it is speculated that the formation of chloroplast and the structure of thylakoid membrane are closely related to pigment content and photosynthetic characteristics, which in turn affect the color and growth of leaves.

**Feasibility of improving leaf color in yellow-leafed plants through hybridization.**

Yellow-leafed plants usually grow significantly weaker than their green-leafed counterparts, which limit their use in landscapes. So, the main aim of yellow-leafed plant breeding programs is to breed yellow-leafed cultivars with strong growth. In our interspecific population of ‘Courtaneur’ × ‘Suwon Gold’, there were visible leaf color segregation and chartreuse-leafed progenies with leaf color between both parents had stronger growth than the yellow-leafed parent ‘Suwon Gold’. Our results have shown that yellow-leafed forsythia may have been caused by the incomplete chloroplast structure, which...
could lead to reduction in the content of photosynthetic pigment, photosynthetic capacity, and growth potential in sequence. Our efforts provided an excellent method and materials for breeding new forsythia cultivars with moderate growth and chartreuse leaves.

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