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Rooting and Overwintering Stem Cuttings of *Stewartia pseudocamellia* Maxim. Relevant to Hormone, Media, and Temperature

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Abstract. ***Stewartia pseudocamellia*** **Maxim. (Japanese Stewartia), a member of Theaceae (tea family), is an excellent garden plant with ornamental features for all four seasons. Reproduction difficulty, however, limits its popularity. We conducted three experiments to ascertain the optimum conditions needed for rooting and subsequent overwintering of semihardwood** ***Stewartia pseudocamellia*** **cuttings. Cuttings were collected in July and prepared for rooting using two types of hormones (KIBA quick dip and Hormodin powder) and three media (Perlite + ProMix, Perlite + Perennial Mix, or Perlite + ProMix + Perennial Mix). Rooted cuttings were overwintered at four different temperatures. The best overwintering temperature was 5 °C, at which 65.6% of newly rooted cuttings survived. Temperatures lower than –12.2 °C were detrimental to the plants. Without cold treatment, only 21.9% of the rooted cuttings survived, which was three times lower than those that received 5 °C treatments. Plants rooted in Perlite + Perennial Mix had 61.8% overwintering survival, which is significantly higher than Perlite + ProMix. The quality of roots, indicated by total root length per cutting, was higher (104.3 cm) with Perlite + Perennial Mix, but not statistically significant. Cuttings treated with rooting hormones had higher rooting percentages (71.9% to 93.6%) as compared with the control (53%). For the same concentration (8000 mg·L^{-1}), liquid (KIBA) and liquid + powder (KIBA + indole-3-butyric acid) rooting hormones resulted in better rooting percentages than powder (Hormodin) alone, although there was no statistical difference in rooting percentages among rooting hormone treatments. The best hormone for subsequent overwintering survival was the combination of quick dip (5000 mg·L^{-1} KIBA) and Hormodin #2 (0.3% a. i.; equivalent to 3000 mg·L^{-1}). It resulted in 64.2% survival, significantly higher than for KIBA quick dip (8000 mg·L^{-1} a.i.) or Hormodin #3 (0.8% a. i.; equivalent to 8000 mg·L^{-1}) alone. Our results suggest that reproduction (rooting and overwintering) of** ***Stewartia*** **was affected by many factors. We recommend rooting** ***Stewartia*** **in media that has good aeration and moderate water-holding capacity and overwintering them at ≈5 °C.**

Stewartia is a member of tea family (Theaceae) and has eight to 21 species depending on authors (Li, 1996; Prince and Parks, 2001; Spongberg, 1974). Japanese Stewartia is a popular ornamental plant with camellia-like flowers, excellent fall color, and exfoliating winter bark (Dirr and Heuser, 1987; Hohn, 1994; Spongberg and Fordham, 1975). This tree performs well in U.S. Department of Agriculture zone 6 to 8, but also grows satisfactorily in zone 5 (Dirr, 1998). Propagation of *Stewartia pseudocamellia* from seed is difficult and time-consuming as a result of complex dormancy mechanisms (Curtis et al., 1996). Seeds are described as "double dormant" with the embryo and its surrounding integuments suspected of maintaining the dormant state (Hartmann et al., 2002). Dormancy can, however, be overcome by desiccation avoidance, gibberellic acid treatment, and warm and cold stratification (Oleksak and Struve, 1999). Propagation by stem cuttings is the most commonly used asexual method to regenerate many woody ornamental plants. There have been a number of attempts to propagate *Stewartia pseudocamellia* by stem cuttings without much success. The limitation, toward cutting propagation of *Stewartia pseudocamellia*, is the difficulty to overwinter the newly rooted cuttings (Flemer, 1982; Perkins and Bassuk, 1995). Cuttings of Japanese Stewartia generally root satisfactorily but fail to successfully overwinter and grow the next spring. In most of the cases, they put forth a new flush of growth, which ultimately ceases to grow and withers off (Smalley and Dirr, 1986; Stimart and Goodman, 1985). Gradual decaying of the root system is also observed. Meanwhile, successful propagation has been carried out in *Stewartia ovata* (Cav.) Weatherby (Curtis et al., 1996). Micropropagation has been successfully carried out in Theaceae using nodal segments as explants (Samartin et al., 1986), although in *Stewartia pseudocamellia*, the process needs to be further investigated to produce multiple microcuttings per nodal segment (McGuigan et al., 1997).

Although sufficient carbohydrate storage is important for winter survival of cuttings (Smalley et al., 1987), starch concentration in stems of the cuttings is not always related to survival (Apine and Kondratovičs, 2005). In Stewartia, insufficient carbohydrates in the cuttings cannot be accounted for low overwinter survival because the cuttings that even grew after rooting did not have higher carbohydrate content in them (Perkins and Bassuk, 1995).

An interesting fact would be to examine the effect of rooting hormone and rooting media overrooting and subsequent overwintering. Higher concentration of auxins could lead to ethylene biosynthesis, increased defoliation, and poor budbreak (Sun and Bassuk, 1993). In *Stewartia ovata*, optimum rooting percentage was recorded at 2000 mg·L^{-1} and 4000 mg·L^{-1} concentrations of indole-3-butyric acid (IBA) (Curtis et al., 1996). Struve and Lagrimini (1999) found that a pretreatment with ascorbic acid and caffeic acid followed by a lower concentration of IBA dip (100 mg·L^{-1}) can provide equally good rooting percentages in *Stewartia pseudocamellia* cuttings. Not much work has been done to study the effect of hormone formulation on rooting and subsequent overwintering.

Overwintering temperature is also a critical factor in successfully overwintering rooted cuttings (Donnelly and Yawney, 1972). Various studies have been initiated in *Acer* (Smalley et al., 1987), *Quercus* (Drew et al., 1993), and *Cornus* (Flemer, 1982) to find the optimum overwintering storage temperature. Air temperatures ranging from 1 to 5 °C have been found optimum for overwintering rooted cuttings of *Stewartia* spp. (Fordham, 1982; Gouveia, 1991, 1995). Curtis et al. (1996) found that the optimum overwintering air temperature and storage duration for *Stewartia ovata* was 6 °C for 10 weeks.

Media plays an important role in the entire process of root growth and development once they have emerged. Rooting media could also affect the overwintering survival rate of the plant. Meldrum (1979) reported that adequate medium aeration was an important factor in successful rooting of camellia. Fordham (1982) and Dirr and Heuser (1987) recommended

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rooting Stewartia cuttings in sand:perlite (1:1, by volume) and allowing the rooted cuttings to overwinter in the same media. Media amendments like dolomitic lime (Curtis et al., 1996) and calcium (Smalley and Avanzato, 1992) did not show any significant effect in rooting when compared with media without amendments. Application of nitrogenous fertilizer before overwinter storage has been found detrimental to successful overwintering (Curtis et al., 1996; Goodman and Stimart, 1987). In this study, we focused on effect of rooting hormone (type and formulation), media characteristics, and overwintering temperature on rooting and surviving of Japanese Stewartia.

Materials and Methods

Overwintering temperature experiment. Semihardwood cuttings of *Stewartia pseudocamellia* were taken from a mature tree at the Arnold Arboretum of Harvard University in Jamaica Plain, MA, on 23 June 2002. All new growth was included and the cutting length ranged from 6 to 15 cm. Cuttings were obtained from branches throughout the canopy and placed in a plastic bag, which was immediately placed in coolers with ice and transported to the University of Maine, Orono.

Cuttings were prepared by cutting off half of the leaf area of individual leaves to reduce transpiration. Basal leaves were stripped off and the basal end of the cutting was slightly wounded by gently scoring with a hand clipper to facilitate the entry of rooting hormone and enhance root initiation. Three centimeters basal of each cutting was given a quick dip in a solution of 8000 mg·L^{-1} KIBA (potassium salt of indole-3-butyric acid; Research Organics, Inc., Cleveland, OH) for 10 s. The cuttings were allowed to air dry for at least 10 min and then inserted in a 5.0 × 5.0 × 6.0-cm^3 cell, which contained Perlite (Whittemore Company Inc., Lawrence, MA) + Perennial Mix (Scotts Sierra Horticulture Products Co., Marysville, OH) in a ratio of 3:1 (by volume). Depth of insertion of cuttings was ≈3 cm. Altogether, 128 cuttings were placed on a mist bench inside the greenhouse. Misting frequency was controlled by a timer (Phytotronics Inc., Earthcity, MO) and set at 20 s every 10 min for the first 2 weeks and then reduced to 20 s every 20 min. Bottom heat (21 °C) was provided for 4 weeks after the cuttings were stuck.

On 24 Sept. 2002, all cuttings were then moved to an outside nursery to acclimate and go dormant under natural ambient conditions. On 15 Nov. 2002, all rooted cuttings were overwintered at four different locations: 1) University of Maine greenhouse (21 °C day/ 15 °C night); 2) University of Maine cooler (5 °C); 3) Western Maine Nursery, overwintering polyhouse in Fryeburg, ME (0 °C); and 4) outside with microfoam coverage. At Fryeburg, cuttings were placed inside a double ploy greenhouse with a supplemental heating system. University greenhouses are glass houses supplied with steam heat. Cuttings kept outside were covered with microfoam on which snow accumulated. Electronic data loggers were placed in all four locations. Cuttings were consolidated from all locations and brought inside the greenhouse on 28 Mar. 2003. Survival rate was recorded based on the emergence of the new growth and health of the cutting.

Rooting hormone experiment. On 27 June 2003, semihardwood cuttings were collected in the same manner as described previously from the Arnold Arboretum of Harvard University in Jamaica Plain, MA. Cuttings were prepared similar to the overwintering temperature experiment and their basal ends were treated with water (control treatment) and three 8000 mg·L^{-1} concentrations of KIBA of different formulations: liquid, powder, or liquid + powder. Liquid formulation comprised of 8000 mg·L^{-1} solution of KIBA in water and powder formulation comprised of the powder form of IBA equivalent to 8000 mg·L^{-1} (Hormodin #3; 0.8% a.i.). The liquid + powder treatment involved first dipping cuttings in a 5000 mg·L^{-1} KIBA solution followed by rolling in powder [Hormodin #2 (Merck & Co., Rahway, NJ); 0.3% a.i.]. A control was also set up by treating the cuttings in distilled water. Cuttings were then stuck in 5.0 × 5.0 × 6.0-cm^3 cells and moved onto the mist bench with bottom heat. A randomized complete block design was adopted with eight replications per treatment. One month before moving the cuttings inside the cooler, the mist was turned off. The chilling requirement of the cuttings was met by placing them in a cooler (5 °C) for a period of 12 weeks starting on 28 Dec. 2003. Inside the cooler they were watered whenever necessary. On 2 Apr. 2004, they were taken out and by the end of the month transplanted into 1-gal pots. Data were recorded for rooting rate (number of cuttings rooted), survival rate, number of roots per cutting, average root length per cutting, and total root length per cutting. Cuttings were fertilized with nitrogenous fertilizer at a low concentration of 50 mg·L^{-1} nitrogen (20N–20P–20K) Peters General Purpose soluble fertilizer (Scotts-Sierra Horticultural Products Co.) twice a week. The concentration was slowly increased to 100 mg·L^{-1} later. Overwinter survival data were taken 1 month after transplanting.

Media experiment. Cuttings obtained on 27 June 2003 were prepared as discussed earlier. Cuttings were treated with a 10-s 8000 mg·L^{-1} KIBA dip before insertion in one of the following three media: 1) Perlite + Perennial Mix in a ratio of 1:1, by volume; 2) Perlite + Perennial Mix + Promix (Premier Horticulture Inc., Quakertown, PA) in a ratio of 2:1:1, by volume; or 3) Perlite + Promix in a ratio of 1:1, by volume. Cuttings were placed on the mist bench as mentioned previously and then moved to coolers for overwintering. After the cuttings were moved out of the coolers, media samples were collected and analyzed for water-holding capacity, pH, and nitrate nitrogen concentrations. All data were analyzed using the general linear model procedure from SAS version 8.1 (SAS Institute Inc., Cary, NC). Mean separation was carried out using the least significant difference method at an alpha 0.05 level.

Results and Discussion

Overwintering temperature. Temperature played an important role in survival and overwintering of newly rooted cuttings. The best overwintering temperature was 5 °C, at which 65.6% of the rooted cuttings survived (Fig. 1). Research done by Curtis et al. (1996) explained that chilling requirement is necessary for both budbreak and shoot growth in *Stewartia ovata*. The duration of the treatment was also critical. They found that 10 to 12 weeks of chilling at 6.1 °C was best for successfully overwintering the cuttings. In our study, best results were obtained when cuttings of *Stewartia pseudocamellia* were overwintered at 5 °C for a 12-week period. Survival percentage of the cuttings overwintered inside the greenhouse (21 °C day/16 °C night) was 21.9%. These cuttings might have received some cold when acclimatized outside (24 Sept. 2003 to 15 Nov. 2003) before being subjected to different overwintering temperature treatments. This survival percentage was three times lower than cuttings that were overwintered at 5 °C. The lowest temperature of –29.4 °C was recorded for the cuttings that were overwintered under microfoam outside. All the cuttings died (Fig. 1). The temperature for cuttings that were overwintered at Western Maine Nursery, Fryeburg, ME, was set at 0 °C. Unfortunately, the supplemental heating system broke down for 1 week and the lowest temperature recorded was –12.2 °C. There was 100% mortality in this case too.

Thus, low temperatures are detrimental to *Stewartia* cuttings during overwintering, because none of the cuttings survived overwintering at –29.4 or –12.2 °C. Generally, ice crystal formation starts in the intercellular spaces at –3 to –5 °C (Taiz and Zeiger, 2002). These crystals continue to grow fed by the gradual withdrawal of water from protoplasts, which remains unfrozen (Taiz and Zeiger, 2002). The ability to withstand low temperatures depends on capacity of the extracellular spaces to accommodate the volume of growing crystals and the ability of the protoplast to withstand hydration.

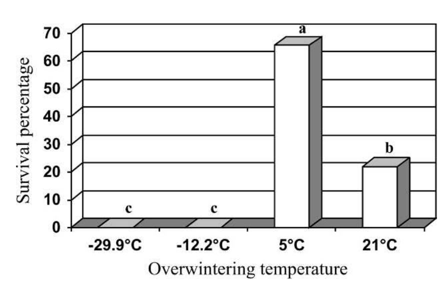

Fig. 1. Percentage survival of *Stewartia pseudocamellia* cuttings at four different overwintering temperatures.

Newly rooted cuttings of *Stewartia*, because of their small size and limited frost-resisting capabilities, perish under severe freezing temperatures. Successful overwintering of *Stewartia pseudocamellia* at 5 °C indicates that a low temperature requirement of the cuttings has to be satisfied for optimum overwintering, which is similar to *Stewartia ovata* (Curtis et al., 1996).

Studies need to be initiated to investigate the lowest overwintering temperature at which the cuttings can be overwintered. Such a study would help in achieving higher survival rates because low temperature during the overwintering period could reduce the amount of carbohydrate used in respiration, thus conserving energy for the new flush of growth in the subsequent spring.

Rooting hormone. Adventitious rooting is determined and controlled by a number of factors like environment (light, temperature, and oxygen), nutrition (carbohydrates, water, macro-, and microelements), and plant health (juvenility, tissue age, and disease status). Our experiment looked at the exogenous application of auxin (KIBA), which would have certainly interacted with all the factors mentioned. Hormone formulations did affect several root characteristics. Spongberg and Fordham (1975) reported that IBA was a good root stimulant for *Stewartia pseudocamellia*, which can be applied as quick dip and also as a talc formulation. In our study, maximum rooting percentage (93.6%) was obtained from a combination of liquid + powder formulation (5000 mg·L^{-1} IBA quick dip followed by 3000 mg·L^{-1} Hormodin #2 powder). The control showed the least rooting percentage (53.0%). Other than control, there was no statistical significance (at alpha 0.05) in rooting percentage among KIBA and IBA treatments (Table 1).Three major root characteristics—number of roots per cutting, average root length, and the total root length—however, showed statistical significance. Despite KIBA treatments having a significant effect on root quality, it did not affect rooting percentages. The average root length per cutting ranged from 1.5 cm for cuttings under control treatment to 3.0 cm for cuttings treated with 5000 mg·L^{-1} KIBA quick dip + 3000 mg·L^{-1} IBA powder. Similarly, there were significant differences in the total root length per cutting, which were 71.9 cm, 26.9 cm, and 12.3 cm for 5000 mg·L^{-1} KIBA quick dip + 3000 mg·L^{-1} IBA powder, 8000 mg·L^{-1} IBA powder, and control treatments.

In all the cases, liquid + powder formulation was the best IBA formulation. The results indicated that 8000 mg·L^{-1} KIBA (quick dip) or 5000 mg·L^{-1} liquid + 3000 mg·L^{-1} powder treatments had higher number of roots as compared with the 8000 mg·L^{-1} IBA powder (Hormodin #3) formulation (Table 1). This might be the result of the difference in absorption between liquid and powder formulations. Interestingly, it has been found that lower concentration of IBA (100 mg·L^{-1}) can also be used in conjunction with caffeic acid and ascorbic acid to root softwood cuttings of *Stewartia pseudocamellia* (Struve and Lagrimini, 1999) because they antagonize the effects of peroxidases, thereby enhancing auxin uptake. However, in general, softwood cuttings are easy to root than semihardwood cuttings. Curtis et al. (1996) used IBA concentrations 4000 mg·L^{-1} for cuttings of *Stewartia ovata* taken in July. Haynes (1999) recorded good rooting percentages in *Stewartia pseudocamellia* with 8000 mg·L^{-1} KIBA quick dip. Sun and Bassuk (1993) found that increasing the concentration of IBA increased the total number of roots in 'Royalty' rose cuttings. However, increased concentrations could inhibit the budbreak as a result of auxin-induced ethylene synthesis because applied auxin is transported to the upper part of the cutting where it causes increased ethylene production (Maynard et al., 1990; Sun and Bassuk, 1993). In case of *Stewartia* budbreak inhibition resulting from a higher concentration of rooting hormone, KIBA (8000 mg·L^{-1}) is not critical because budbreak before overwinter storage does not have any significant affect on the overwinter survival of cuttings (Perkins and Bassuk, 1995). Moreover, the effect the ethylene produced will remain only until the rooting period of the cutting, which in the case of *Stewartia* is between 30 and 45 d.

For hormonal treatments, initial survival rates (recorded on 28 Apr. 2004) were higher than control. Among the hormonal treatments, quick dip + powder had higher survival rate than powder alone. Initially, there was no statistical difference in the survival rates between quick dip and quick dip + powder treatment, but at the final evaluation (overwinter survival rate), quick dip + powder had significantly higher overwinter survival rate (recorded on 14 June 2004). It varied from 27.9% (8000 mg·L^{-1} KIBA quick dip) to 64.2% (5000 mg·L^{-1} KIBA quick dip + 3000 mg·L^{-1} powder). Initial survival rate was calculated based on number of cuttings that survived (condition of roots not taken into consideration). Overwinter survival was assessed based on overall health and active growth of the new flush. Overwinter survival rate was lower than the initial survival rate because some cuttings died by the time of final evaluation as a result of poorly developed and degenerating root system. There is a clear indication that overwinter survival of an individual cutting is influenced by both quantitative and qualitative attributes of its root system that are prerequisites for successful establishment in future years. Our study, thus, demonstrates that when comparing control, powder, and powder + quick dip treatments, we notice a significant difference in the overwinter survival rate.

Media study. Both the physical and chemical composition of the media brought about significant changes in the overwinter survival rate of the cuttings. Overwinter survival rate was very poor, 2.8%, for the cuttings stuck in Perlite + Promix. The highest overwinter survival rate of 61.8% was obtained with Perlite + Perennial Mix followed by 10.2% for Perlite + Promix + Perennial Mix. There was no statistical significance for overwinter survival rate between Perlite + Promix + Perennial Mix and Perlite + Promix (Table 2). The percentage merely tripled when Perennial Mix was added to Perlite + Promix and became ≈20 times when only Perennial Mix was used with Perlite. Characters determining root quality do not show any statistical significance.

Laboratory analysis of the three media formulations shows different levels of nitrate-N levels (Table 3). Perlite + Perennial Mix had the highest nitrate-N level (20.0 mg·L^{-1}) followed by Perlite + Promix + Perennial Mix (11.0 mg·L^{-1}) and Perlite + Promix (less than 0.01 mg·L^{-1}). These data were statistically significant. In their experiment conducted on *Eucalyptus globulus*, Schwambach et al. (2005) found that rooting media with nitrate produced healthy white

Table 1. Rooting, survival, and overwinter survival rate, number of roots, average root length, and total root length per cutting of semihardwood cuttings of *Stewartia pseudocamellia* as affected by hormone type and concentration.

	Treatments			
Parameter	Control	8000 mg·L^{-1} KIBA (quick dip)[z]	8000 mg·L^{-1} IBA (powder)[y]	5000 mg·L^{-1} KIBA (quick dip) + 3000 mg·L^{-1} IBA (powder)[x]
Rooting rate (%)	53.0 b[w]	90.6 a	71.9 a	93.6 a
Survival rate[v] (%)	25.4 c	50.0 ab	43.6 b	78.1 a
Overwinter survival rate[u] (%)	5.0 c	27.9 b	26.9 b	64.2 a
Number of roots per cutting	4.1 c	20.0 a	8.7 b	22.7 a
Average root length (cm) per cutting	1.5 c	2.3 b	2.0 b	3.0 a
Total root length (cm) per cutting	12.3 c	57.5 a	26.9 b	71.9 a

[z]Solution prepared using potassium salt of IBA; cuttings dipped for 10 s in the hormone solution.
[y]Base of the cuttings smeared with Hormodin #3, powder formulation of IBA.
[x]Base of the cuttings dipped in 5000 mg·L^{-1} KIBA solution then smeared with Hormodin #2 (3000 mg·L^{-1}), powder formulation of IBA.
[w]Mean separation of values within rows by Fisher's least significant difference test ($P \leq 0.05$).
[v]Percentage survival at first evaluation on 28 Apr. 2004.
[u]Percentage survival of cuttings on 14 June 2004.
IBA = indole-3-butyric acid.

Table 2. Rooting rate, survival rate, overwinter survival rate, number of roots per cutting, average root length per cutting, and total root length per cutting of semihardwood cuttings of *Stewartia pseudocamellia* as affected by different media compositions.

	Treatments		
Characteristics	Perlite + Promix[z]	Perlite + Promix + Perennial Mix[y]	Perlite + Perennial Mix[z]
Rooting rate (%)	87.5 a	81.3 a	90.6 a[x]
Survival rate[w] (%)	15.6 a	31.3 b	75.0 a
Overwinter survival rate[v] (%)	2.8 b	10.2 b	61.8 a
Number of roots per cutting	27.4 a	27.9 a	34.2 a
Average root length (cm) per cutting	2.9 a	2.4 a	2.6 a
Total root length (cm) per cutting	95.7 a	84.4 a	104.3 a

[z]Media mixed 1:1, volume/volume.
[y]Media mixed 2:1:1, volume/volume/volume.
[x]Mean separation of values within rows by Fisher's least significant difference test ($P \leq 0.05$).
[w]Percentage survival at first evaluation on 28 Apr. 2004.
[v]Percentage survival of only rooted cuttings from the first evaluation. Data recorded on 14 June 2004.

Table 3. Water-holding capacity, pH, and soluble nitrate concentration of different media formulations used for overwintering *Stewartia pseudocamellia* cuttings.

	Treatments		
Characteristics	Perlite + Perennial Mix[z]	Perlite + Promix + Perennial Mix[y]	Perlite + Promix[z]
Water-holding capacity (as % by weight)	156.4 a[x]	186.8 b	234.7 c
pH	5.9 a	6.1 b	6.2 b
Nitrate-N (as % soluble salts; $mg \cdot L^{-1}$)	20.0 a	11.0 b	<1.0 c

[z]Media mixed 1:1, by volume.
[y]Media mixed 2:1:1, by volume.
[x]Mean separation of values within rows by Fisher's least significant difference test ($P \leq 0.05$).

roots, which are often indicative of high physiological activity. On the contrary, with increasing nitrate concentration, there was a significant decrease in root length. Decrease in root length was observed in our experiment too, but it was not statistically significant.

According to Meldrum (1979), there was a direct relationship between the aeration of the media and rooting of cuttings. Studies of various media have revealed that physical characteristics of media such as particle size were less deterministic of rooting performance than air and water content (Tilt and Bilderback, 1987). Media with more aeration ensured better rooting, minimal rotting, and ultimately a better overwinter survival percentage. The water-holding capacity (WHC) of the media inversely depicts the media aeration. There were significant differences in WHCs among the three media. Perlite + Perennial Mix, being a more bark-based media, had the minimal WHC, and thus more aeration, followed by Perlite + Promix + Perennial Mix and Perlite + Promix (Table 3). WHC was calculated as percentage by weight of the media. The overwinter survival in Perlite + Perennial Mix was almost three and 20 times higher when compared with Perlite + Promix + Perennial Mix and Perlite + Promix, respectively. Increased aeration in Perlite + Perennial Mix, ensured adequate growth and development of roots and better establishment of the cutting.

Medium pH is also an important factor that determined successful propagation (Long, 1932). Perlite + Perennial Mix had the lowest pH of 5.9, which was statistically significant when compared with the pH of the other two media (Table 3). For optimum growth of *Stewartia pseudocamellia*, the pH of the soil should be 5.5 to 6.5 (Dirr, 1998). Not much work has been undertaken to study the effect of pH on the overwinter survival of *Stewartia*. We observed that cuttings of *Stewartia pseudocamellia* prefer low pH for both root and shoot development because the cuttings propagated in Perlite + Perennial Mix (pH 5.9) had a healthy root system and a vigorous flush of growth when moved outside the greenhouse the next summer, indicating better overwinter survival rate (data not presented).

Overwintering of *Stewartia pseudocamellia* is, thus, controlled by a number of factors that has to be managed carefully, especially rooting hormone application, rooting media, and overwintering temperature. The better hormone application for *Stewartia pseudocamellia* cuttings is a quick dip in 5000 $mg \cdot L^{-1}$ KIBA solution followed by powder application of 3000 $mg \cdot L^{-1}$ Hormodin #2. We recommend Perlite + Perennial Mix (1:1, by volume) as the best media for successfully overwintering the newly rooted cuttings of *Stewartia pseudocamellia*. All newly rooted cuttings should be overwintered within a temperature range of 3 to 5 °C for maximum overwinter survival. At the same time, aspects of cutting maturity and health, time of propagation, and propagation environment should also be taken into consideration. Of course, the genetic constitution of the plant is also an indispensable factor that would influence the entire process of rooting and successful overwintering. Further studies are needed to understand why stem necrosis occurs on the stem above the rooting zone but below the level of rooting medium in the rooted cuttings of *Stewartia* (Wilson and Struve, 2004). *Stewartia* trees growing outdoors have been reported to be infested with fungal pathogens (Gajda et al., 2002). These pathogens can overwinter along with cuttings and later grow and develop in the spring, causing the stem to rot. There are reports of a large number of fungi attacking the seedlings of *Stewartia pseudocamellia* (Gajda et al., 2002). A total number of 132 colonies of fungi growing on weak and infected seedlings of *Stewartia pseudocamellia* have been reported (Gajda et al., 2002).

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