Cultivar, Photoperiod, and Gibberellin Influence Shoot Elongation and Photosynthetic Capacity of Hardy Azaleas

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Abstract. In a greenhouse experiment involving 13 hardy azalea (*Rhododendron* spp.) cultivars, 'Noordthiana' and 'Treasure' had the highest rate of shoot elongation and the highest photosynthetic capacity (Pcap) during the summer. In winter, 'Treasure' had a high rate of shoot elongation and Pcap, but 'Noordthiana' had a high rate of shoot elongation and low Pcap. Long days or GA₃ sprays stimulated shoot elongation but not Pcap of certain cultivars. GA₃ was effective in stimulating shoot elongation of 'Vuyk's Scarlet' if plants were given supplemental photoperiods under natural winter (short) photoperiods. Cultivars with a high rate of shoot elongation and Pcap likely will produce salable plants in a shorter time period than slower growing cultivars because less time elapses between prunings. Production time can be decreased further with GA₃ sprays, especially with GA₃ applications in combination with supplemental photoperiods during the short days of winter. Chemical name used: gibberellic acid (GA₃).

The rate of shoot elongation may be an important factor in the year-round greenhouse production of azaleas. A faster rate of shoot elongation would reduce time between prunings. Production schedules developed by Batson (1975) for greenhouse azaleas indicate that two-thirds of total production time is devoted to shoot growth and development. Earlier reports indicate that the shoot elongation (enlargement) rate in azaleas may be influenced by cultivar (Ballantyne, 1991; Ceulemans et al., 1984; Pettersen, 1972), photoperiod (Pettersen, 1972), and GA₃ sprays (Sink and Walker, 1964).

Hardy azaleas rather than greenhouse cultivars have been used in these studies. Hardy cultivars may be produced under protected cultivation (Larson, 1993; Stadtherr, 1975).

Ceulemans et al. (1984) found a positive relationship between apparent photosynthesis and shoot elongation in a few genetically related Belgian indica (greenhouse) cultivars. However, in two hardy (landscape) azalea cultivars that were not genetically related to each other, such a relationship did not occur (Ballantyne, 1991). In these studies, cultivars that are not closely related to one another were studied. Photosynthetic capacity (Pcap) has been determined with the Clark O₂ electrode (YSI, Silver Spring, Md.) (Ballantyne, 1991).

The objectives of this study are to determine 1) the influence of cultivar, GA₃, and supplemental photoperiods on shoot elongation of hardy azaleas and 2) whether there is a

relationship between shoot elongation and Pcap in hardy azaleas.

Materials and Methods

One-year-old plants of various hardy azalea cultivars (Table 1) growing in a loam supplemented with compost and peatmoss were dug in the field and potted into 15-cm-diameter (1.41-liter) azalea pots with 1 peat : 1 sand (v/v) and placed in a greenhouse held at 16 ± 1°C nights. No soil was removed from the plants before potting. The number of plants dug varied, depending on the requirements of the experiment. All plants were dug and potted 3 weeks before pruning, whether the experiment was in the summer or in the winter. In the greenhouse, daytime maxima ranged from 25°C in winter to 40°C in summer (daytime mean in summer was 30°C). In summer, the maximum photosynthetic photon flux (PPF) was 900

μmol·m⁻²·s⁻¹, the mean midday PPF was 588 ± 312, and in winter the respective values were 450 and 126 ± 108, as determined with a LI-COR Quantum Sensor (LI-COR, Lincoln, Neb.). In the greenhouse, a night break during November and to the end of the appropriate experiments was provided by 60-W incandescent bulbs from 8:00 PM to 4:00 AM, providing 10 μmol·m⁻²·s⁻¹ at plant level for a long-day effect with a supplemental photoperiod. Photoperiods during the winter have been recommended by Batson (1975) and were found by Pettersen (1972) to increase shoot length. Plants were fertilized monthly with 100 ml ammonium sulfate (21% N) (2.6 g·liter⁻¹) and 20N–20P–20K (20N–8.8P–16.6K) (Green Valley Fertilizer, Surrey, B.C.) (0.75 g·liter⁻¹). After the plants had been in the greenhouse 3 weeks, all shoots were cut back to allow four to six leaves to remain (counting from the base of the shoot). GA₃ was employed at 0.3 mM because that concentration provided maximum stem elongation in a preliminary dose-response experiment. Where GA₃ (in 0.1% Tween 20; both from Sigma Chemical Co., St. Louis) was applied, six weekly sprays were used. Controls were treated with 0.1% Tween 20. Spraying to runoff began 3 weeks after plants were pruned, when shoot initiation could be determined visually. Shoot elongation was measured 10 weeks after pruning on all new lateral shoots. Plants were considered to be ready to be pruned when 80% or more of the shoots were at least 9 cm long.

Pcap determinations were made using the youngest fully expanded leaves on shoots 10 to 12 weeks old. Pcap of sixteen 25-mm² leaf segments was measured with the Clark O₂ electrode (Ballantyne, 1991). These determinations may be made in 30 to 40 min, involve compact and relatively economical equipment, and require small amounts of tissue (400 mm²/determination). Sixteen leaf disks, 4 mm in diameter, were isolated from four leaves with a cork borer; each disk was cut in half and placed in 4.8 liters of 50 mM N-(2-hydroxyethyl) piperazine-N1-(2-ethane sulfonic acid) (HEPES) and 0.5 mM CaSO₄ at pH 7.2. Leaf segments were vacuum-infiltrated

Table 1. Azalea cultivars employed in these studies.

Cultivar	Group ^a	Parentage ^a
Amagasa	Satsuki	<i>Rhododendron indicum</i> (L.) seedling of Huzan
Buccaneer	Glenn Dale	Hinodegiri x Late Salmon
Caroline Gable	Gable	[<i>R. yedoense</i> var. <i>poukhanense</i> Nakai x (Hexe)] x (<i>R. yedoense</i> var. <i>poukhanense</i> Nakai x <i>R. kaempferi</i> Planch.)
Fashion	Glenn Dale	<i>R. indicum</i> (L.) x Momozono
Florida	Vuyk	Unknown seedling x Vuyk's Scarlet
Girard's Hot Shot	Girard	El Capitan x Aladdin
Hershey's Red	Hershey	Unknown
Hirocriston	Kurume	Amoenum x Hinodegiri
Hinodegiri	Kurume	<i>R. 'Obtusum'</i> hybrid
Noordthiana (Rosea)	Southern	Sport of Mucronatum
	Indian	
Rosebud	Gable	Louise Gable x Caroline Gable
Treasure	Glenn Dale	Fielder's White x <i>R. kaempferi</i> Planch.
Vuyk's Scarlet	Vuyk	Unknown

^aAccording to Galle (1985).

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twice (to avoid excessive bubbling) for 3 min with a water aspirator at 0.96 MPa. Leaf segments were given 10 min of illumination with $1400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ using a Prado (Leitz, Midland, Ont.) slide projector as a light source. Following the initial illumination, 0.1 ml NaHCO_3 (final concentration 12.5 mM) was added and O_2 uptake and evolution were determined with a YSI model 53 Clark O_2 electrode at $2000 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and 30°C. Determinations were made on a chlorophyll basis, rather than on a leaf area basis, removing some of the effects of leaf morphology from comparisons between cultivars. Chlorophyll concentrations of the leaf segments were obtained using 96% ethanol (Wintermans and De Mots, 1965).

All experiments were randomized block experiments with four replications. Each replication consisted of a single plant. Differences between means were tested at $P \leq 0.05$ using Duncan's multiple range test.

Results and Discussion

When determinations were made over the summer months, the two cultivars ('Noordthiana' and 'Treasure'), of 13 cultivars tested, with the highest rate of shoot elongation over 10 weeks also were among those with high Pcap (Table 2). (In this experiment, all cultivars had less shoot elongation than 'Noordthiana'.) However, the relationship between Pcap and shoot elongation of other cultivars was not as pronounced and there were many exceptions. Few of these cultivars were closely related (Table 1). When determinations were made during the winter, 'Noordthiana' and 'Treasure' had a high rate of shoot elongation, but only 'Treasure' had a high Pcap ('Noordthiana' had a very low Pcap during that period) (Table 3). Pcap may be important in determining shoot elongation in 'Treasure' but not in other cultivars I studied. Supplemental photoperiods during natural winter (short) photoperiods stimulated the rate of shoot elongation in azalea cultivars, but did not have a detectable effect on Pcap (Table 3). In the summer, GA_3 sprays stimulated shoot elongation but had little effect on Pcap (Table 4). Thus, GA_3 does not directly influence photosynthesis. If any significant amount of shoot elongation is to be realized during winter months in the greenhouse, a supplemental low PPF photoperiod is required. During the short photoperiods of winter, GA_3 sprays are effective only if applied under supplemental photoperiods (Table 4).

Cultivars with a high rate of shoot elongation have less elapsed time between prunings (Table 5), especially in the winter, when compared with cultivars that have a lower rate of shoot elongation. 'Treasure', which had the most rapid rate of shoot elongation, has a pronounced advantage over other cultivars in this regard. Gibberellic acid sprays decreased the time between prunings of most cultivars; this effect also is more pronounced during the winter with supplemental photoperiods, i.e., long days (Table 5).

Cultivar, GA_3 , and supplemental photoperiods all influenced shoot elongation in azaleas

Table 2. Shoot elongation and photosynthetic capacity (Pcap) of azalea cultivars, Summer 1991.

Cultivar	Shoot elongation over 10 weeks (cm)	Pcap $\mu\text{mol O}_2/\text{mg}$ chlorophyll per h
Hinocrimson	5.5 f ²	65.3 a-c ³
Amagasa	6.4 ef	50.9 b-d
Hershey's Red	6.5 ef	46.3 cd
Hinodegiri	6.5 d-f	67.4 a-c
Vuyk's Scarlet	7.8 de	56.7 b-d
Rosebud	7.9 de	58.7 bc
Buccaneer	8.2 d	50.9 b-d
Florida	9.8 c	53.0 b-d
Girard's Hot Shot	10.1 c	59.4 cd
Caroline Gable	10.2 c	52.6 b-d
Fashion	10.8 c	35.2 d
Treasure	13.0 b	69.0 b
Noordthiana	15.6 a	83.5 a

²Mean separation within columns at $P \leq 0.05$ by Duncan's multiple range test for four replications.

³Correlation coefficient between shoot elongation and Pcap (r) = + 0.29 for 13 cultivars significant at $P \leq 0.05$.

Table 3. Shoot elongation and photosynthetic capacity (Pcap) of azalea cultivars, under natural days (ND) and ND + supplemental photoperiods (LD).

Cultivar	Photoperiod	Shoot elongation over 10 weeks (cm)	Pcap $\mu\text{mol O}_2/\text{mg}$ chlorophyll per h
<i>Sept.-Dec. 1990</i>			
Hinocrimson	ND	2.6 c ²	45.3 ab
Hershey's Red	ND	3.6 c	35.7 ab
Vuyk's Scarlet	ND	3.9 bc	52.0 a
Fashion	ND	5.1 b	33.0 b
Caroline Gable	ND	5.2 b	31.9 b
Treasure	ND	6.6 a	53.7 a
<i>Nov. 1991-Jan. 1992</i>			
Vuyk's Scarlet	ND	2.4 d	42.9 a
	LD	4.7 c	41.4 a
Rosebud	ND	0.8 e	38.3 a
	LD	5.2 c	39.5 a
Caroline Gable	ND	2.5 d	36.1 a
	LD	7.7 b	43.1 a
Noordthiana	ND	2.8 d	12.3 b
	LD	10.4 a	15.7 b

²Mean separation within columns and time periods at $P \leq 0.05$ by Duncan's multiple range test for four replications.

Table 4. Shoot elongation and photosynthetic capacity (Pcap) of azalea cultivars sprayed with 0.3 mM GA_3 .

Cultivar	GA_3	Photoperiod ²	Shoot elongation over 10 weeks (cm)	Pcap $\mu\text{mol O}_2/\text{mg}$ chlorophyll per h
<i>June-Aug. 1991</i>				
Vuyk's Scarlet	-	ND	8.7 c ³	48.8 a
	+	ND	11.9 b	42.8 ab
Fashion	-	ND	11.2 b	37.6 b
	+	ND	14.9 a	38.6 b
<i>Nov. 1991-Feb. 1992</i>				
Vuyk's Scarlet	0	ND	1.3 c	
	+	ND	1.6 c	
	0	LD	3.8 b	
	+	LD	9.0 a	

²ND = natural day; LD = ND + supplemental photoperiods.

³Mean separation within columns and time periods at $P \leq 0.05$ by Duncan's multiple range test for four replications.

leas (Tables 2, 3, and 4), but photosynthesis does not have a dominant influence on shoot elongation. 'Noordthiana' and 'Treasure' had a high rate of shoot elongation during the summer and winter. Cultivars such as 'Hinocrimson', 'Vuyk's Scarlet', and 'Hershey's Red' had a low rate of shoot elongation during summer and winter. During the winter, shoot elongation was stimulated by supplemental photoperiods. Gibberellic acid

sprays stimulated shoot elongation during the summer, and during the winter, when plants received a supplemental photoperiod. Any factor that results in a high rate of shoot elongation can reduce elapsed time between prunings, decreasing the time of production. Rate of shoot elongation may be only one factor in determining time of production of azaleas. The number of lateral breaks per shoot is also a significant factor in producing azaleas

Table 5. Effect of 0.3 mM GA₃ sprays on number of days between the first and second prunings of azalea cultivars.²

Cultivar ^y	GA ₃	June–Aug. 1992	Oct. 1992–Jan. 1993 (under long days)
Fashion	–	54.4 a ^x	100 bc
	+	49.0 cd	93.6 d–f
Vuyk's Scarlet	–	52.4 ab	114 a
	+	50.4 bc	102 bc
Hershey's Red	–	54.8 a	103 b
	+	49.0 cd	93.6 d–f
Caroline Gable	–	50.8 bc	95.4 c–e
	+	48.2 d	88.2 f
Rosebud	–	54.4 a	98.8 b–d
	+	49.0 cd	91.2 ef
Treasure	–	45.0 e	88.6 f
	+	45.0 e	76.2 g

²Plants were pruned when 80% of the shoots were at least 9 cm long.

^yOf these cultivars, 'Treasure' has the most rapid rate of shoot elongation (Tables 2 and 3).

^xMean separation within columns at $P \leq 0.05$ by Duncan's multiple range test for five replications.

in a minimum time. Results with GA₃ support those of Sink and Walker (1964), who worked with seedlings of other *Rhododendron* species. If GA₃ is applied during the winter, supplemental light will be required to achieve a stimulation of shoot elongation by GA₃.

Shoot elongation and Pcap are related to each other in the case of some cultivars. 'Noordthiana' and 'Treasure' have a high rate of shoot elongation and high Pcap. During the summer, all cultivars, except 'Hinocrimson' and 'Hinodegiri', had lower Pcap than 'Noordthiana', which had the most shoot elongation (Table 2). However, in the 13-cultivar experiment there was a low positive correlation between Pcap and shoot elongation (Table 2). Supplemental photoperiods and GA₃ stimulated shoot elongation but had little effect on Pcap. While Ceulemans et al. (1984) detected a close relationship between photosynthesis and cultivars, they were working with closely

related cultivars (their cultivar with a low rate of shoot elongation and photosynthesis was a parent of their cultivar with high rates of shoot elongation and photosynthesis). While shoot elongation requires photosynthesis, each process is complex, involving many unique proteins, and each is connected by translocation. Thus, I am not surprised that the relationship between the two processes may be weak, depending on the cultivars being compared. Pcap had less influence on shoot elongation than either cultivar or supplemental photoperiods during winter, or GA₃. Probably, shoot (sink) metabolism, which may be influenced by GA₃ or photoperiod (possibly phytochrome), is more important than source (photosynthetic) metabolism in determining shoot elongation. Our current understanding of the mode of action of GA₃ or photoperiod on plant growth indicates that each of these may act by stimulating m-RNA and protein synthesis.

Cultivars with a high rate of shoot elongation may be grown faster, especially in the wintertime, when compared with cultivars that have a lower rate of shoot elongation (Table 5). The cultivar Treasure has a pronounced advantage over other cultivars in this regard. Gibberellic acid sprays may decrease the time between prunings of most cultivars, and again this effect is more pronounced during the winter in the presence of supplemental light (Table 5).

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