Eastern White Pine Flowering in Response to Spray Application of Gibberellin $A_{4/7}$ or Procone™

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ABSTRACT: *Eastern white pine (*Pinus strobus *L.) is an important forestry species in the northeastern and midwestern United States and in eastern Canada. Induction of early and reliable flowering and cone production will shorten the breeding cycle and aid in the development of genetically improved white pine. The objective of this study was to determine if a foliar spray application of gibberellin $A_{4/7}$ ($GA_{4/7}$) or ProCone™ would induce both male and female strobili on young grafted eastern white pine selected for white pine blister rust resistance. Trees were sprayed (500 mg L^{-1}) weekly in 1998 during the period of rapid shoot elongation (mid-May through July), for a total of 11 applications. Flowering data were collected June 15, 1999. Twenty-five out of 53 genotypes produced male strobili. For all genotypes studied, the total number of male strobili clusters per tree (and the mean number ±SE of pollen-cones per cluster) produced with $GA_{4/7}$, ProCone™, or untreated controls were: 643 (7.1 ± 0.3); 574 (7.9 ± 0.3); and 79 (8.3 ± 0.8), respectively. Twenty out of 53 genotypes produced female strobili. For all genotypes studied, the total number of female strobili per tree (and the mean number ± SE of female strobili per shoot) produced with $GA_{4/7}$, ProCone™, or untreated controls were: 87 (1.1 ± 0.1); 130 (1.3 ± 0.1); and 33 (0.6 ± 0.1), respectively. Eleven genotypes produced both male and female strobili. Control trees that flowered may have been the result of spray drift. The results indicate that a foliar spray application of $GA_{4/7}$ or ProCone™ at 500 mg L^{-1} will induce both male and female strobili, but not on all selected genotypes of eastern white pine. North.J. Appl. For. 19(2):68–72.*

Key Words: *Pinus strobus*, pollen cone, seed cone.

Eastern white pine (*Pinus strobus* L.), in Minnesota, is ecologically and economically valuable, providing timber, bird nesting habitats, safe havens for wildlife, and a historical role in forest ecology. Reforestation efforts in Minnesota have been hampered because of eastern white pine's susceptibility to several biotic and abiotic stress factors, the most challenging being white pine blister rust (WPBR) disease. WPBR can cause high losses both in regeneration and in immature timber stands. One method of overcoming the mortality caused by WPBR is to develop genetic resistance to the disease. This can be accomplished through selection and breeding of promising individual trees. The breeding process can be accelerated by inducing earlier flowering and seed production. The ability to induce early and abundant flowering in eastern white pine will shorten the breeding period from 10 to 15 yr to possibly 5 yr or less. In combination with other ongoing WPBR research, this is a critical element in quickly testing and deploying material that is genetically resistant to WPBR.

In northern Minnesota, several white pine orchards have been established with field grafts of eastern white pine from selected trees with putative WPBR resistance. The grafts generally do not produce staminate and ovulate strobili (pollen cones and seed cones) for several years, and initially, most grafts bear seed cones. Pollen cone and seed cone production on grafted eastern white pine trees occurs irregularly and in small numbers (Ahlgren 1972, Ho and Schnekenburger 1992). In clonal seed orchards established with sexually mature scions, significant seed production does not normally occur before ages 6 to 8 (Bonnet-Masimbert and Webber 1995). The pattern of flowering in eastern white pine is quite variable (Murphy and Miller 1979, Wendel and Smith 1990). Few or no male strobili with moderate amounts of pollen appear during the early flowering years (5 to 10 yr of age), but female strobili can persist on older trees. Sexually

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mature trees do not produce good crops of pollen and seed cones every year, and the interval between large seed crops can range from 3 to 10 yr (average 3 to 5 yr) (Krugman and Jenkinson 1974, Vidakovic 1991, Wendel and Smith 1990).

The induction of flowering in conifers in response to exogenous application of GAs (specifically $GA_{4/7}$) is well documented (Bonnet-Masimbert 1987, Bonnet-Masimbert and Zaerr 1987, Brockerhoff and Ho 1997, Eysteinsson and Greenwood 1995, Pharis 1991, Pharis et al. 1987, Ross and Pharis 1987, Shearer et al. 1999, Smith 1998). Cultural treatments, such as root pruning, stem or branch girdling, fertilizing, and water stress, along with site and environmental conditions, significantly affect certain species increased responsiveness to $GA_{4/7}$ (Bonnet-Masimbert 1987, Daoust et al. 1995, Fogal et al. 1999, Pharis et al. 1987, Ross 1992, Smith and Greenwood 1995, 1997, Wheeler and Bramlett 1991). The rate, timing, mode of application, time of year, and location of treatments on the tree also have an important effect on the sex of the flowers.

Gibberellin $A_{4/7}$ promotes flowering in *Pinus*, and several species have been found to respond to $GA_{4/7}$ applied by foliar sprays, topical application, or stem injection (Cecich 1981, 1983, Cecich et al. 1994, Dickson et al. 1999, Eriksson et al. 1998, Fogal et al. 1994, 1995, 1996, 1999, Greenwood 1981, 1982, Hare 1984, Harrison and Slee 1991, Ho and Hak 1994, Siregar and Sweet 1996, Sweet 1979, Wesoly 1987, Wheeler and Bramlett 1991). In general, when $GA_{4/7}$ is used as a foliar spray, the concentration ranges from 100 to 600 mg L^{-1}, with repeated treatments (sprayed weekly or every other week) during the period of rapid shoot elongation (Bonnet-Masimbert 1987, Bonnet-Masimbert and Zaerr 1987, Cecich 1983, 1985, Cecich et al. 1994, Daoust et al. 1995, Eysteinsson and Greenwood 1995, Fogal et al. 1994, 1995, 1999, Hare 1984, Ho and Hak 1994, Marquard and Hanover 1984, Wesoly 1987). Gibberellin $A_{4/7}$ has been reported effective in promoting pollen cone and seed cone production in potted and field-grown grafts of eastern white pine (Ho 1996, Ho and Eng 1995, Ho and Schnekenburger 1992). Results of these studies indicate that treatments for pollen cone and seed cone production are best carried out during the period of rapid lateral shoot elongation. Routine stimulation of flowering in eastern white pine using other techniques, such as crown thinning, fertilizer application, root pruning, and girdling has been largely unsuccessful (Hocker 1962, Schmidtling 1983, Stephens 1964). ProCone™ is a plant growth regulator formulation, containing $GA_{4/7}$ in a proprietary solvent, that may promote pollen cone and seed cone production for tree improvement programs and operational seed orchards (Abbott Labs 1997). The objective of this study was to determine if a foliar spray application of $GA_{4/7}$ or ProCone™ applied during the period of lateral shoot elongation would induce both male and female strobili on grafted eastern white pine selected for WPBR resistance.

Site Description

The study area is a University of Minnesota eastern white pine breeding orchard located in Cloquet, MN (Carlton County). Chemical and physical characteristics of the site (average of four soil samples) were: soil pH 5.5, organic matter 0.95 %, sand 87.8 %, silt 4.3 %, clay 7.9 %, extractable phosphorus 45.3 mg kg^{-1}, nitrate nitrogen 0.4 mg kg^{-1}, exchangeable calcium 145.5 mg kg^{-1}, exchangeable magnesium 19.5 mg kg^{-1}, exchangeable sodium 3.3 mg kg^{-1}, and exchangeable potassium 27.8 mg kg^{-1}. The average annual precipitation is 76 cm, 30 cm of which falls during May through July (on-site weather station). The average temperatures for May, June, and July are 11.1, 16.1, and 19.3°C, respectively. In 1998, the total precipitation was 84 cm, of which 32 cm fell during May through July. In 1998, the average temperatures for May, June, and July were 14.8, 15.8, and 19.7 °C, respectively.

Methods

White pine ramets grafted from trees selected for resistance to WPBR were planted in three-tree row plots (north to south) at 3 × 3 m spacing. The orchard was established in 1991 (through 1993) and consisted of over 150 families. Trees in this orchard had not previously flowered, except for a small number (7.5%) producing female strobili. Based on uniformity of tree size within clones, 53 genotypes (5 to 7 yr old) were selected for whole-tree spraying with $GA_{4/7}$ (one ramet), ProCone™ (one ramet), or unsprayed Control (one ramet). Trees were sprayed (500 mg L^{-1}) weekly in 1998 during the period of shoot elongation (mid-May through July) for a total of 11 applications. Gibberellin $A_{4/7}$ and ProCone™ were purchased from Abbott Labs, North Chicago, IL. The purity of the technical-grade $GA_{4/7}$ was analyzed by gas chromatography-mass spectrometry (R.P. Pharis, University of Calgary, pers. comm.) with resulting analysis of: 72.9% GA_4, 18.4% GA_7, and 3.7% GA_9. ProCone™ contains $GA_4 + GA_7 = 4.0\%$ w/w per liter of proprietary solvent (additional analysis unavailable). Solutions (500 mg L^{-1} each)) of $GA_{4/7}$ or ProCone™ in 15% ethanol plus 0.05% Aromox C/12 cationic surfactant (Akzo Nobel Chemicals, Inc., Chicago, IL) were sprayed (mist until runoff) on trees using a compressed air sprayer. In June of the year following treatments, flowering data were collected. The number of female and male strobili per shoot for all trees was recorded. The total number of male strobili per cluster was also recorded. Data analyses were performed on the results using SYSTAT (SPSS, Inc.).

Results

Trees treated with either $GA_{4/7}$ or ProCone™ at 500 mg L^{-1} during the period of rapid shoot elongation produced more male (Figure 1) and female (Figure 2) strobili than control trees. However, not all WPBR-selected genotypes of eastern white pine produced cones. Trees sprayed with $GA_{4/7}$ or ProCone™ produced significantly more male strobili clusters (1,217) than female strobili (217). Twenty-five out of 53 genotypes (47%) produced male strobili (Table 1). The total number (all trees) of male strobili clusters and the mean number (±SE) of pollen-cones per cluster produced with $GA_{4/7}$, ProCone™, or untreated

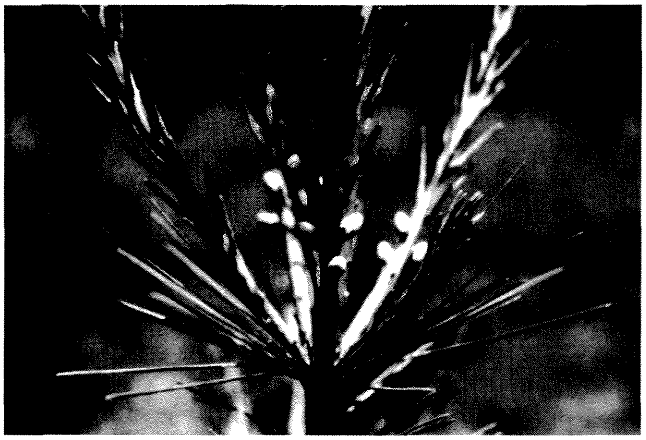

Figure 1. ***Pinus strobus*** **shoot with male strobili.**

Figure 2. ***Pinus strobus*** **shoot with female strobili.**

controls were: 643, 7.1 ± 0.3; 574, 7.9 ± 0.3; and 79, 8.3 ± 0.8, respectively. The total number of male strobili clusters and the mean number of pollen cones per cluster did not significantly differ between $GA_{4/7}$ or ProCone™ treated trees, as compared to controls. There were differences in the number of male strobili clusters induced within a genotype. For example, genotype #10 had 45 male strobili clusters produced on the ramet sprayed with ProCone™ versus zero produced on the ramet sprayed with $GA_{4/7}$. Genotype #2950 had 325 male strobili clusters produced on the ramet sprayed with $GA_{4/7}$ versus only 48 produced on the ramet sprayed with ProCone™. There were also differences in the number of male strobili clusters induced among genotypes. For $GA_{4/7}$, the greatest number of male strobili clusters (325) were produced on genotype #2950, whereas, genotype #2210, 5211, 1640, 2840, 10, 4531, 580, 40, and 6550 did not produce any male strobili clusters. For ProCone™, the greatest number of male strobili clusters (109) were produced on genotype #2560, whereas, genotype #7170, 3881, 10280, 5270, 40, 6200, and 6550 did not produce any male strobili clusters. Control trees (13%) that produced male strobili clusters were most likely the result of spray drift, as trees in this orchard had not previously produced any male (pollen cone) strobili.

Twenty out of 53 genotypes (38%) produced female strobili (Table 2). For all genotypes studied, the total number

Table 1. Number of male strobili (pollen cone) clusters and mean number (±SE) of pollen cones per cluster on eastern white pine trees sprayed with $GA_{4/7}$, ProCone™, or control trees.[a]

	$GA_{4/7}$		ProCone™		Control	
Genotype number	No. of clusters	Cones per cluster	No. of clusters	Cones per cluster	No. of clusters	Cones per cluster
310	1	2	2	7.5 ± 4.5	0	0
2210	0	0	2	5.5 ± 1.5	0	0
240	39	3.7 ± 0.5	47	25.1 ± 1.9	1	1
1040	20	6.2 ± 0.9	11	3.9 ± 1.0	0	0
2950	325	7.3 ± 0.4	48	12.4 ± 1.8	0	0
2940	59	5.7 ± 0.4	37	5.5 ± 0.6	0	0
2490	96	11.6 ± 0.9	41	7.1 ± 0.8	0	0
10300	5	8.8 ± 2.8	83	6.7 ± 0.6	0	0
7170	1	1	0	0	0	0
5211	0	0	6	5.5 ± 1.6	0	0
2560	73	6.6 ± 0.6	109	6.9 ± 0.5	65	14.3 ± 1.0
3881	5	10.2 ± 3.3	0	0	0	0
1640	0	0	15	6.7 ± 0.9	0	0
2840	0	0	24	6.3 ± 1.0	1	5
3551	7	4.1 ± 0.6	15	3.5 ± 0.4	1	10
10280	1	2	0	0	3	5.3 ± 1.2
7160	3	6.3 ± 1.8	20	6.1 ± 1.5	0	0
5270	5	6.6 ± 2.3	0	0	0	0
10	0	0	45	7.8 ± 0.8	0	0
4531	0	0	7	3.1 ± 0.6	0	0
580	0	0	9	3.1 ± 0.7	0	0
40	0	0	0	0	2	2.5 ± 0.5
10750	2	10.5 ± 6.5	53	6.2 ± 0.6	0	0
6200	1	2	0	0	0	0
6550	0	0	0	0	6	9.0 ± 3.4
Total	643	7.1 ± 0.3	574	7.9 ± 0.3	79	8.3 ± 0.8

[a] Trees sprayed with 500 mg L^{-1} of $GA_{4/7}$ or ProCone™ weekly from mid-May through July 1998. Control trees were left unsprayed. Flowering data collected June 15, 1999.

Table 2. Number of female strobili (seed-cone) per tree and mean number (±SE) of seed cones per shoot on eastern white pine trees sprayed with $GA_{4/7}$, ProCone™, or control trees.[a]

	$GA_{4/7}$		ProCone™		Control	
Genotype number	No. of clusters	Cones per cluster	No. of clusters	Cones per cluster	No. of clusters	Cones per cluster
3100	3	1.3 ± 0.3	0	0	0	0
4500	0	0	1	1	0	0
1040	3	1.3 ± 0.3	0	0	3	1
500	2	1	3	1.7 ± 0.3	0	0
10300	4	1.8 ± 0.3	2	1	0	0
2560	0	0	4	1	7	1.4 ± 0.2
2690	17	1.7 ± 0.2	21	2.6 ± 0.3	0	0
2840	28	1.6 ± 0.1	48	1.4 ± 0.1	8	1.4 ± 0.3
2841	0	0	4	1	0	0
3120	6	1.2 ± 0.2	9	1.3 ± 0.2	0	0
6900	3	1.3 ± 0.3	4	1.8 ± 0.5	3	1.7 ± 0.3
3551	3	1	7	1.6 ± 0.2	6	1.3 ± 0.2
10280	2	2	0	0	0	0
5270	4	1	5	1.2 ± 0.2	0	0
10	0	0	4	1.5 ± 0.3	0	0
2470	0	0	0	0	2	1.5 ± 0.5
2170	10	1.4 ± 0.2	10	2.3 ± 0.2	4	1.5 ± 0.3
10750	0	0	8	1.9 ± 0.2	0	0
6200	1	5	0	0	0	0
6550	1	3	0	0	0	0
Total	87	1.1 ± 0.1	130	1.3 ± 0.1	33	0.6 ± 0.1

a Trees sprayed with 500 mg L^{-1} of $GA_{4/7}$ or ProCone™ weekly from mid-May through July 1998. Control trees were left unsprayed. Flowering data collected June 15, 1999.

of female strobili and the mean number (±SE) of female strobili per shoot produced with $GA_{4/7}$, ProCone™, or untreated controls were: 87, 1.1 ± 0.1; 130, 1.3 ± 0.1; and 33, 0.6 ± 0.1, respectively. The total number of female strobili and the mean number of female strobili per shoot did not significantly differ between $GA_{4/7}$ or ProCone™ treated trees, as compared to controls. There were no significant differences in the number of female strobili induced within a genotype, except for genotype #2840. Genotype #2840 had 28 female strobili produced on the ramet sprayed with $GA_{4/7}$ versus 48 produced on the ramet sprayed with ProCone™. There were differences in the number of female strobili induced among genotypes. For $GA_{4/7}$, the greatest number of female strobili (28) were produced on genotype #2840, whereas, genotype #4500, 2560, 2841, 10, 2470, and 10750 did not produce any female strobili. For ProCone™, the greatest number of female strobili (48) were produced on genotype #2840, whereas, genotype #3100, 1040, 10280, 2470, 6200, and 6550 did not produce any female strobili. It is difficult to assess whether or not control trees (13%) that produced female strobili were the sole result of spray drift, as a few trees (7.5%) in this orchard had previously produced a small number of female strobili, but no specific number of strobili per tree had been recorded.

Eleven genotypes (21%) produced both male and female strobili (Table 1,2). Of these 11 genotypes, only genotype #6550 had male strobili produced on the control tree when no male strobili were produced on the ramets sprayed with $GA_{4/7}$ or ProCone™.

Discussion

This study demonstrated that there was a genotypic effect on flowering in 5- to 7-yr-old eastern white pine, when $GA_{4/7}$ or ProCone™ was used as a foliar spray (500 mg L^{-1}) during the period of rapid shoot elongation (May through July) in northern Minnesota. Out of 53 genotypes studied, 47% of the trees produced male strobili, 38% female strobili, 21% both male and female strobili, and only 13% of the controls flowered. This was a significant finding, as trees in this orchard had not previously flowered, except for a small number of trees (7.5%) producing female strobili. No significant (uniform) increase in strobili production for all genotypes that flowered occurred when comparing $GA_{4/7}$ to ProCone™. Hare (1984) reported that three biweekly foliar sprays of 200 mg L^{-1} $GA_{4/7}$ were optimal for promotion of pollen cone buds in 12-yr-old loblolly (*Pinus taeda* L.), slash (*P. elliottii elliottii* Engelm.), and longleaf (*P. palustris* Mill.) pine. Seed cone bud production was sparse. Greenwood (1982) reported the female flowering response of 3-yr-old grafted mature scions of loblolly pine (*P. taeda* L.) to $GA_{4/7}$ was proportional to the log of its concentration, but no significant effect on male flowering was observed. Wesoly (1987) reported a significant increase in the number of male flowers and to some extent female flowers in 17-yr-old Scots pine (*P. sylvestris*) when 200 mg L^{-1} $GA_{4/7}$ was applied as a single application. Ho and Hak (1994) reported the best treatment for both pollen cone and seed cone production in 3-yr-old jack pine (*P. banksiana* L.) was weekly spraying at 400 or 600 mg L^{-1} $GA_{4/7}$ from early July through August in Ontario. Ho and Eng (1995) using 17 genotypes (4-yr-old grafts), reported that a foliar spray of $GA_{4/7}$ (500 mg L^{-1}) applied during May–June (in Ontario) increased pollen cone production, but did not promote seed cone production in eastern white pine, as compared to controls. Sixty-nine percent of their trees produced pollen cones, 50% seed cones, but no percentage was reported for trees producing both male and female strobili. The percentage of control trees (unsprayed) that flowered (63 for pollen cones and 69 for seed cones) was extremely high and reported to be a result of shifting of the wind during spray application (Ho and Eng 1995). In our study we were able to keep spray drift to a minimum by monitoring weather patterns weekly, spraying early in the day, and controlling the spray mist to individual trees. This type of treatment regime may prove useful in a breeding program carried out on young progeny where strobili production is limited. Results of this study are promising, but our research continues in this area to investigate the alternative technique of stem injection of $GA_{4/7}$ during various times of the year, in order to produce optimal male and female strobili production in all of our WPBR-selected genotypes.

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