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Effects of Treatment and Seed Source on Germination of Eastern Redcedar Seed

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Abstract

Germination of eastern redcedar (*Juniperus virginiana* L.) seeds was best with a 96-hour soak in citric acid (10,000 ppm), with 6 weeks of moist-warm (24°C) stratification, and 10 weeks of moist-cold (5°C) stratification. Geographic seed sources responded differently to treatment. Use of fresh seeds could reduce the time in moist-warm stratification, would improve germination, and would reduce interaction between seed source and treatment.

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Management Implications

Eastern redcedar (*Juniperus virginiana* L.) is the major component in many of the windbreaks, wildlife, environmental, and esthetic plantings throughout the Great Plains. However, despite past research and the millions of eastern redcedar seedlings grown and distributed annually throughout the region, it is often difficult to germinate the seed. There is a need to formulate a clear procedure to achieve quick and reliable germination of eastern redcedar seed.

Results of this research show that reliable germination of eastern redcedar seed can be achieved with a 96-hour soak in citric acid (10,000 ppm), 6 weeks in moist-warm (24°C), and 10 weeks moist-cool stratification (5°C); and that geographic sources of seed respond differently to treatment. This information will help conduct management programs and research studies.

Introduction

Eastern redcedar is the most widely distributed indigenous conifer species in the Great Plains. It occurs in most of the eastern half of South Dakota, extending into the southwestern corner of North Dakota; then southward through all but far western Nebraska, most of Kansas and Oklahoma (excluding the Panhandle), and into northwestern and through much of eastern Texas (Little 1971).

Eastern redcedar seeds have characteristics which make germination erratic and unpredictable. The seeds have a thick and semi-impermeable coat that must be conditioned to imbibe water; and have dormant embryos that must after-ripen before germination can occur (Pack 1921a, 1921b; Gerbracht 1937; Afanasiev and Cress 1942). If they are not treated, only a few seeds germinate the first year, most germinate the second year, and a few the third year.

Barton (1951) reported that a 90-day moist-cool (5°C) period of stratification was required to break embryo dormancy and permit germination. She reported that failure to obtain complete germination after optimum low temperature treatment was a result of the impermeability of seed coats in a large percent of the seeds.

Efforts to increase the permeability of seed coats have included soaking eastern redcedar seed (and seeds of other conifers) in sodium-lye (Webster and Ratliffe 1942), alcohol and boiling water (Chadwick 1946), concentrated sulfuric acid (Barton 1951, Andresen 1965), citric acid (Cotrufo 1963), and hydrogen peroxide (Trappe 1961, Stein 1965, Riffle and Springfield 1968); and freezing seeds in ice (Jelley 1937). Seeds also have been subjected to abrasive scarification prior to soaking in hydrochloric acid, pepsin, and alkaline solutions (Jelley 1937); and seeds have been moist-warm stratified in various media, at different temperatures, and for various lengths of time (Parker 1950, Barton 1951, Afanasiev 1955, Engstrom 1955, Johnsen 1959, Wycoff 1961, Meines 1965, and Benson 1976). This study evaluated pre-germination treatments of eastern redcedar seed; the objectives were to identify those treatments which would best achieve predictable and uniform germination in the shortest time, and to study the response of seed source to treatment.

Materials and Methods

The effects of treatments on the germination of eastern redcedar seeds were evaluated in two experiments. The first tested a wide range of treatments on seeds of a single source; the second tested some of the treatments used in the first experiment on seeds from different geographic sources (provenances).

In both experiments, germination counts were made weekly, and cumulative germination percentages were calculated 28 days after moist-cool stratification. Seeds were counted as germinated when the radicle extended 1 mm from the seed coat. Data were converted, using the arcsin transformation, prior to analysis of variance to stabilize any heterogeneous variance. Testing levels for rejection of the null hypotheses were $P = 0.05$.

Experiment 1

Twenty-two treatments were selected involving combinations of soaking seeds in water, hydrogen peroxide (30%), sulfuric acid (conc.), and citric acid (10,000 ppm) for various times; followed by moist-warm (24°C) and moist-cool (5°C) stratification for various periods of time (table 1).

Seeds collected in the fall of 1977, near Anselmo, in central Nebraska (41°35′N., 99°50′W.), were obtained from the USDA Forest Service Bessey Nursery at Halsey, Nebr. All treatments were started simultaneously in April 1979 and were evaluated at the end of treatments. Seeds receiving moist-warm (24°C) treatments were: (1) soaked in appropriate solutions; (2) wrapped in cheese cloth; and, (3) packed between layers of finely sieved and dampened peat in one-pint, perforated plastic baskets. The baskets were (1) suspended over trays of water; (2) placed in moist-warm (24°C) stratification; and (3) transferred to moist-cool (5°C) stratification as listed in table 1.

Following moist-cool stratification, seeds were placed onto moistened filter paper in six sterilized round petri dishes (25 seeds per dish), and were placed in an incubator at 24°C.

Table 1.—Experiment 1: Percent germination of one geographic seed source of *Juniperus virginiana* seeds under various treatments of soaking, and periods of moist-warm (24°C) and moist-cool (5°C) stratification.[1]

Soak treatment No.	Soak treatment Duration	Period of stratification at 24°C	Percent germination[2] after period of stratification at 5°C (weeks)-- 0	6	8	10	12	14	$\bar{x}$[3]
	time	*weeks*	*percent*						
Water									
1	30 min.	0	0.0	10.7	11.3	8.0	13.3	15.3	11.7
2	30	2	2.7	48.7	57.3	54.0	48.7	70.7	55.9
3	30	4	3.3	37.3	35.3	45.3	54.7	36.7	41.9
4	30	6	2.0	36.0	46.7	68.0	58.0	71.3	56.0
5	30	8	1.3	24.7	40.7	41.3	72.0	71.3	50.0
Hydrogen peroxide									
6	15 min.	0	0.0	3.3	12.0	23.3	16.7	26.0	16.3
7	30	0	0.0	6.0	11.3	7.3	12.7	14.0	10.3
8	45	0	0.0	0.0	0.6	0.0	1.3	1.3	0.6
9	60	0	0.0	1.3	5.3	4.0	3.3	6.0	4.0
10	30 min.	2	8.0	50.7	44.7	54.0	61.3	70.0	56.1
11	30	4	2.7	31.3	30.0	49.3	49.3	56.0	43.2
12	30	6	0.7	22.0	45.3	10.7	--	--	26.0
13	30	8	7.3	42.0	56.0	60.7	78.7	68.0	61.1
Sulfuric acid									
14	20 min.	0	8.7	9.3	24.0	32.7	36.0	27.3	25.9
15	30	0	4.0	5.3	18.7	40.7	40.0	29.3	26.8
16	40	0	5.3	8.7	24.7	34.7	36.0	30.7	27.0
Citric acid									
17	96 hr.	0	0.0	2.0	2.7	2.7	0.7	3.3	2.3
18	96	2	0.0	34.0	35.3	49.3	52.7	48.0	43.9
19	96	4	2.0	46.0	47.3	56.0	54.7	68.7	54.5
20	96	6	4.0	54.7	65.3	72.0	77.3	82.7	70.4
21	96	8	6.0	40.7	58.7	58.0	58.0	70.7	57.2
Water									
22	96 hr.	6	2.7	46.0	64.0	64.7	72.0	66.7	62.7
		$\bar{x}$ =	2.8	25.5	33.5	38.0	42.7	44.5	

[1]*Moist-warm treatments preceded moist-cool treatments.*

[2]*Basis: 150 seeds (6 subsamples of 25 seeds each).*

[3]*Treatment means do not include the zero weeks stratification at 5°C.*

Experiment 2

In 1982, eight treatments were tested (table 2). All treatments, except treatments 7 and 8, were installed as follows: (1) seeds from each source were mixed separately with finely screened and sterilized sand, were placed in sterilized plastic four-ounce containers, and were moistened with sterilized water; (2) containers were placed in moist-warm 24°C stratification for 4, 6, or 8 weeks; (3) containers with seeds were transferred at 4-, 6-, or 8-week intervals to 10 or 12 weeks of moist-cool (5°C) stratification; (4) seeds were washed from sand in containers, and 200 seeds of each source were plated onto four sterilized square plastic petri dishes (50 seeds per dish) containing a 1% water-agar substrate; (5) petri dishes were placed in 24°C incubation until germination; and (6) numbers of germinated seeds were counted every 7 days until the 28th day. In treatments 7 and 8, the seeds first were immersed for 96 hours in a 10,000 ppm solution of citric acid before being stratified. Treatments were installed on an adjusted schedule so that the 5°C moist-cool stratification would end simultaneously for all treatments.

Nine sources of eastern redcedar seeds were selected for this experiment from a single-tree (half-sib) seed collection made throughout the Great Plains in 1973–75. These sources represented a north-south sampling through the central and southern Great Plains (fig. 1). The cones of these seed sources had been depulped and the seeds were held dry in cold storage at –16°C (Van Haverbeke and Barnhart 1978). One of the sources represented a re-collection from one of the trees (1023–3) in 1982. In both experiments, the plating of the seed onto the petri dishes constituted subsamples rather than true replications, because the separate dishes assessed variation within seed rather than separate applications of treatments.

Table 2.—Experiment 2: Percent germination of *Juniperus virginiana* seed sources under various treatments of soaking and periods of moist-warm (24°C) and moist-cool (5°C) stratification.[1]

Treatment no.[2]	Seed source no.	Soak and duration	Period of stratification at 24°C	Germination after stratification at 5°C (weeks)-- 10	12
		hours	*weeks*	------*percent*------	
1 and 2[3]	651-3	None	4	0.0	35.0
	661-2	None	4	0.0	0.0
	751-1	None	4	9.0	47.0
	752-2	None	4	16.0	8.0
	761-3	None	4	16.0	35.0
	781-4	None	4	0.0	38.5
	841-2	None	4	0.5	18.5
	1023-3	None	4	0.0	0.5
	1023-3'82	None	4	39.0	44.5
				$\bar{x}$=8.9	25.2
3 and 4	651-3	None	6	0.0	22.0
	661-2	None	6	1.0	0.0
	751-1	None	6	25.0	33.5
	752-2	None	6	53.0	33.0
	761-3	None	6	2.5	43.0
	781-4	None	6	12.5	21.0
	841-2	None	6	1.5	8.0
	1023-3	None	6	0.0	4.0
	1023-3'82	None	6	47.5	64.5
				$\bar{x}$=15.9	25.4
5 and 6	651-3	None	8	26.0	40.0
	661-2	None	8	5.5	0.5
	751-1	None	8	45.0	30.0
	752-2	None	8	75.0	59.0
	761-3	None	8	37.5	45.0
	781-4	None	8	21.5	45.5
	841-2	None	8	24.0	33.0
	1023-3	None	8	1.5	1.0
	1023-3'82	None	8	65.5	44.0
				$\bar{x}$=33.5	33.2
		Citric acid			
7 and 8	651-3	96 hr.	6	17.0	6.5
	661-2	96 hr.	6	29.5	2.5
	751-1	96 hr.	6	61.0	10.0
	752-2	96 hr.	6	48.0	25.5
	761-3	96 hr.	6	64.0	25.0
	781-4	96 hr.	6	77.0	35.5
	841-2	96 hr.	6	23.0	15.0
	1023-3	96 hr.	6	12.0	0.5
	1023-3'82	96 hr.	6	57.5	42.0
				$\bar{x}$=43.2	18.1

[1]*Moist-warm treatments preceded moist-cool treatments.*

[2]*Treatment numbers refer to number of weeks at 5°C; i.e., treatments 1, 3, 5, and 7 =10 weeks at 5°C; treatments 2, 4, 6, and 8 = 12 weeks at 5°C.*

[3]*Basis: 200 seeds (4 subsamples of 50 seeds).*

Results

Experiment 1

The best germination was obtained with treatments incorporating citric acid, water, or hydrogen peroxide (table 1). Treatment 20 (96-hour soak in citric acid, 6-week moist-warm (24°C) stratification) promoted the best germination, although not significantly better than treatments 13, 21, and 22 (table 1).

The zero-week moist-cool (5°C) stratification induced very little germination; these data were removed from the analysis (table 1). A plot of the data showed very little interaction between pretreatments and the amount of moist-cool stratification once the zero-week at 5°C stratification data were removed. Therefore, the pretreatment x stratification at 5°C interaction was used as the error term for testing the null hypotheses. In this experiment, the term "pretreatment," as distinguished from the term treatment used throughout, refers to combinations of

soak and moist-warm (24°C) stratification preceding moist-cool stratification at 5°C.

The effect of moist-cool (5°C) stratification is characterized as a linear increase in germination of about 5% for each 2 weeks of stratification (fig. 2). Contrasts for the moist-cool (5°C) stratification means showed there were no significant differences between 12 and 14 weeks, or between 10 weeks and the combination of 12 and 14 weeks stratification. The combination of 6, 8, and 10 weeks compared to 12 and 14 weeks stratification, however, was significantly different, as was 6 vs. 14 weeks stratification.

Experiment 2

Seed sources responded differently to different treatments. Thus, the treatment x seed source interaction could not be used as the error term, as in the analysis in experiment 1. Data were analyzed using a technique

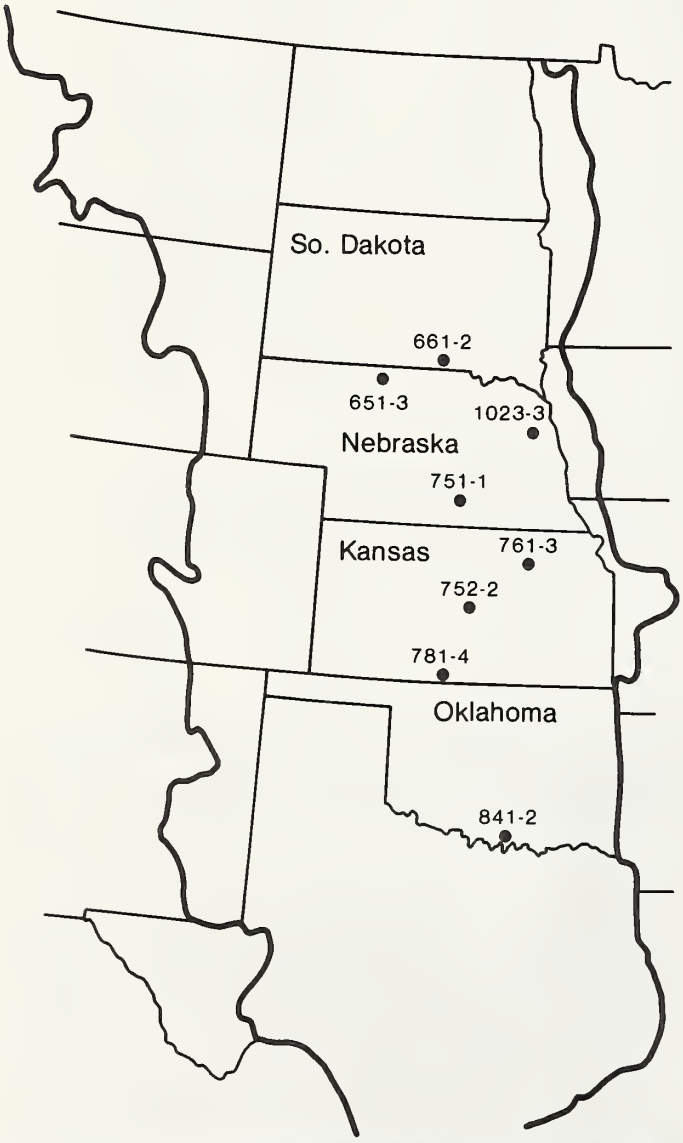

Figure 1.—Distribution of *Juniperus virginiana* seed sources in the central Great Plains.

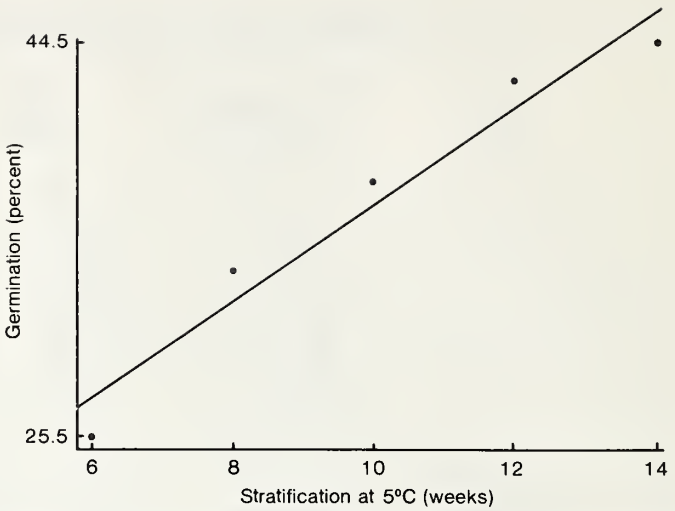

Figure 2.—Mean percent germination of eastern redcedar seeds at various weeks of moist-cool (5°C) stratification.

for assessing differences among many proportions (Fleiss 1981), in which seed sources were compared within a treatment, and treatments were compared within a seed source (tables 3 and 4).

There were wide differences in the germination potential of the different sources; some sources were more responsive to seed treatments than others. Sources 761–3, 752–2, 781–4, and 751–1 had relatively high germination rates for some treatments; source 1023–3 '82, had relatively good germination with nearly all of the treatments (table 3).

Treatment 7 (96 hrs citric acid; 6 wks 24°C and 10 wks 5°C stratification) produced the best overall germination, with mean germination percentages of 43.3 for all sources (table 4). The results obtained in treatment 7 demonstrated consistency with those obtained in experiment 1. Treatments 5, 6, 4, and 2 yielded lower mean germination percentages of 33.5, 33.2, 25.3, and 25.3, respectively.

The ability of treatment 7 to stimulate germination, and the ability of sources 751–1, 752–2, 761–3, 781–4, and 1023–3 '82 to germinate was apparent; they appeared 24 times among the 26 best, significantly similar, all treatment-source combinations (tables 3 and 4).

Discussion and Recommendation

Percent germination of eastern redcedar seeds was zero or below 10% unless preceded by moist-warm (24°C) and a moist-cool (5°C) stratification (table 1). Germination averaged only 2% over all treatments with zero weeks at either or both stratification temperatures (table 1). This is in agreement with Pack (1921a), who reported germination of non-afterripened seed (also with no prior soak) to be only about 1%. As few as 2 weeks stratification at 24°C, followed by 10 weeks at 5°C, increased average germination to 52%. Extension of the 24°C stratification period to 4 and 8 weeks, with 12 weeks at 5°C yielded average germination percentages of 53 and 70, respectively. Similar percentages of 34 and 77 were reported by Barton (1951) for the same periods of moist-warm (24°C) and moist-cool (5°C) stratification.

Table 3.—Experiment 2: Percent germination of *Juniperus virginiana* seed for treatments within sources.

Seed source	Treatment no.	Percent germination[1]
651-3	3	0.0 a
	1	0.0 a
	8	6.5 ab
	7	17.5 bc
	4	22.0 cd
	5	26.0 cd
	2	35.0 *de*
	6	40.0 *e*
		$\bar{x}$ = 16.3
661-2	4	0.0 a
	1	0.0 a
	2	0.0 a
	6	0.5 a
	3	1.5 a
	8	2.5 a
	5	5.5 a
	7	29.5 b
		$\bar{x}$ = 4.4
751-1	1	9.0 a
	8	10.0 a
	3	25.0 b
	6	30.0 bc
	4	33.5 bc
	5	45.0 c
	2	47.0 cd
	7	61.0 d
		$\bar{x}$ = 28.9
752-2	2	8.0 a
	1	16.0 ab
	8	25.5 bc
	4	33.0 cd
	7	48.0 de
	3	53.0 e
	6	59.0 *ef*
	5	75.0 f
		$\bar{x}$ = 35.3
761-3	3	2.5 a
	1	16.0 b
	8	25.0 bc
	2	35.0 cd
	5	37.5 cd
	4	43.0 d
	6	45.0 d
	7	64.0 *e*
		$\bar{x}$ = 29.8
781-4	1	0.0 a
	3	12.5 b
	4	21.0 bc
	5	21.5 bc
	8	35.5 cd
	2	38.5 d
	6	46.5 d
	7	77.0 *e*
		$\bar{x}$ = 28.1
841-2	1	0.0 a
	3	1.5 ab
	4	8.0 bc
	8	15.0 cd
	2	18.5 cde
	5	24.0 de
	7	24.0 de
	6	33.0 e
		$\bar{x}$ = 13.8
1023-3	3	0.0 a
	1	0.0 a
	2	0.5 a
	8	0.5 a
	6	1.0 a
	5	1.5 a
	4	3.0 ab
	7	12.0 b
		$\bar{x}$ = 2.1
1023-3'82	1	39.0 a
	8	42.0 ab
	6	44.0 ab
	2	44.5 ab
	3	47.5 abc
	7	57.5 bc
	4	64.5 c
	5	65.5 c
		$\bar{x}$ = 44.9

[1]*Percentages with different letters are significantly different at P = 0.05.*

Table 4.—Experiment 2: Percent germination of *Juniperus virginiana* seed for sources within treatments.

Treatment no.	Seed source	Percent germination[1]
1	651-3	0.0 a
	661-2	0.0 a
	781-4	0.0 a
	1023-3	0.0 a
	841-2	0.5 a
	751-1	9.0 b
	752-2	16.0 b
	761-3	16.0 b
	1023-3'82	39.0 b
		$\bar{x}$ = 8.9
2	661-2	0.0 a
	1023-3	0.5 ab
	751-2	8.0 bc
	841-2	18.5 cd
	651-3	35.0 de
	761-3	35.0 de
	781-4	38.5 e
	1023-3'82	45.5 e
	751-1	47.0 e
		$\bar{x}$ = 25.3
3	651-3	0.0 a
	1023-3	0.0 a
	661-2	1.0 a
	841-2	1.5 a
	761-3	2.5 ab
	781-4	12.5 bc
	751-1	25.0 c
	1023-3'82	47.5 d
	752-2	53.0 d
		$\bar{x}$ = 15.9
4	661-2	0.0 a
	1023-3	3.0 ab
	841-2	8.0 bc
	781-4	21.0 cd
	651-3	22.0 d
	752-2	33.0 d
	751-1	33.5 *de*
	761-3	43.0 *e*
	1023-3'82	64.5 *e*
		$\bar{x}$ = 25.3
5	1023 -3	1.5 a
	661-2	5.5 a
	781-4	21.5 b
	841-2	24.0 b
	651-3	26.0 b
	761-3	37.5 bc
	751-1	45.0 c
	1023-3'82	65.5 d
	752-2	75.0 d
		$\bar{x}$ = 33.5
6	661-2	0.5 a
	1023-3	1.0 a
	751-1	30.0 b
	841-2	33.0 b
	651-3	40.0 bc
	1023-3'82	44.0 bc
	761-3	45.0 bc
	781-4	46.5 bc
	752-2	59.0 c
		$\bar{x}$ = 33.2
7	1023-3	12.0 a
	651-3	17.0 ab
	841-2	24.0 ab
	661-2	29.5 bc
	752-2	48.0 cd
	1023-3'82	57.5 d
	751-1	61.0 de
	761-3	64.0 de
	781-4	77.0 e
		$\bar{x}$ = 43.3
8	1023-3	0.5 a
	661-2	2.5 ab
	651-3	6.5 abc
	751-1	10.0 bc
	841-2	15.0 cd
	761-3	25.0 de
	752-2	25.5 de
	781-4	35.5 *e*
	1023-3'82	42.0 *e*
		$\bar{x}$ = 18.1

[1]*Percentages with different letters are significantly different at P = 0.05.*

Germination of seeds treated with sulfuric acid, without moist-warm stratification, was not satisfactory (table 1). This contrasts with the results obtained by Barton (1951); but is not disappointing, because sulfuric acid is a high-danger chemical—one probably best avoided in the interest of safety in most work situations.

Seeds in treatment 7 (citric acid) of experiment 2 germinated nearly three times better than seeds in treatment 3 (no soak) of experiment 2 with percentages of 43.2 vs. 15.9, respectively (table 2). The effect of citric acid may account for the difference. Average percent germination decreased from 43.2% in treatment 7 to 18.1% in treatment 8 of experiment 2. This decrease, while at variance with the 82.7% germination achieved in treatment 20 of experiment 1, suggests a detrimental influence of a total stratification period extending beyond 16 weeks (6 wks at 24° and 10 wks at 5°C). This decrease in germination percent was consistent within treatments 7 and 8 for all nine seed sources.

Barton (1951) also found that 2 to 8 weeks of moist-warm stratification, or a 16-week total stratification period was best. The moist-cool stratification at 5°C beyond 12 weeks was not desirable, because germination began before the end of stratification, and the young seedlings might be injured in planting.

Cotrufo (1963) reported 93% germination, with fresh seed, following a 96-hour soak in citric acid (10,000 ppm), zero weeks of moist-warm stratification, and 12 weeks of moist-cool (3°C) stratification. The high germination percentage attained by Cotrufo, with the omission of a moist-warm stratification period, may have been attributable to his use of fresh instead of stored seed. Meines (1965) suggested that seed held in storage is drier and, thus, may be less permeable. Also, seed of southeastern origin, as perhaps used by Cotrufo, tends to be smaller, with thinner seed coats than seed from northerly origins used in the present experiments and by Barton (1951); such southeastern seed may be more permeable. Eastern redcedar trees in the Great Plains contain clinally distributed amounts of Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) germplasm—a species with larger seed and with thicker seed coats (Van Haverbeke 1968).

Results of the present experiments, and those of Barton (1951), who also used the Anselmo, Nebr. seed source, indicate that about 16 weeks, in some combination of a minimum of 4 weeks stratification at 24°C and a maximum stratification of 12 weeks at 5°C, are required to achieve satisfactory germination of eastern redcedar seed of Great Plains origin. The 62% seed germination reported by Barton (1951) for the Anselmo, Nebr. seed source is in the same magnitude achieved in the present experiments.

Consistent with results in experiment 1, treatment 7 in experiment 2 yielded the best overall results with most seed sources. Germination also was better for all seed sources in treatment 7 than in treatment 8; indicating the additional 2 weeks of 5°C stratification is undesirable (table 2). This effect was more pronounced in the dry/cold stored seed of source 1023–3 than in the fresh dry seed of source 1023–3 '82. The detrimental effect of the additional 2 weeks of moist-cool (5°C) stratification was not as noticeable in the non-citric acid treatment.

The following treatment, based on these results, is recommended to achieve germination of Great Plains sources of eastern redcedar in greenhouse containerized operations:

1. Use the freshest seeds available,
2. Soak seeds in citric acid (10,000 ppm) for 96-hours,
3. Place seeds in moist-warm (24°C) stratification for 6 weeks,
4. Place seeds in moist-cool (5°C) stratification for 10 weeks.

Seeds treated this way also would be well-conditioned for a spring sowing in outdoor nursery beds. However, nursery sowing of dry, stored seeds in mid-July accomplishes moist-warm stratification, and the over-winter period accomplishes moist-cool stratification for successful early spring germination (Wycoff 1961, Meines 1965).

The results of experiment 2 would have been more definitive had it contained a water-soak treatment prior to stratification. Treatment 22 in experiment 1, while lower in percent germination, was not significantly different than treatment 20 (table 1).

The interaction between seed sources and treatments, which occurred in all sources except the fresh sample of source 1023–3 '82 is of interest. The contrast between germination percentages of fresh vs. stored seeds, plus the good germination of fresh seeds regardless of treatment, further emphasizes the advantage of using fresh seeds to minimize source x treatment interaction, and to achieve maximum and uniform germination. This aspect is important for production of seedlings for management programs from different seed sources, and for tree improvement research studies that routinely involve tests of multi-provenance origin.

The sampling of seed sources was not extensive in experiment 2; however, there was a trend for seeds of the same age from the central Great Plains (sources 751, 752–2, 761–3, and 781–4) to achieve higher germination percentages than sources closer to the northern (1023–3, 651–3, and 661–2) and southern (841–2) peripheries of the species distribution within the central Great Plains (tables 2, 3, and 4).

Literature Cited

Afanasiev, M. 1955. Storage of afterripened seed of eastern redcedar. Tree Planters' Notes 21:28–30.

Afanasiev, M., and M. Cress. 1942. Change within the seeds of *Juniperus scopulorum* during the processes of after-ripening and germination. Journal of Forestry 40:798–801.

Andresen, J. W. 1965. Stratification of seed of *Pinus strobiformis*. Tree Planters' Notes 72:5–7.

Barton, L. V. 1951. Germination of seeds of *Juniperus virginiana* L. Contributions of Boyce Thompson Institute 16:387–393.

Benson, D. A. 1976. Stratification of *Juniperus scopulorum*. Tree Planters' Notes 27(2):11, 23.

Chadwick, L. C. 1946. Seeds of redcedar. American Nurseryman 83(9):10.

Cotrufo, C. 1963. Stimulation by citric acid of germination of eastern red cedar (*Juniperus virginiana* L.). Nature 199:92–93.

Engstrom, A. 1955. Polyethylene film for seedbed mulch. Tree Planters' Notes 21:25–26.

Fleiss, J. L. 1981. Statistical methods for rates and proportions. 2nd ed. John Wiley and Sons, New York, Chap. 9, p. 138–159.

Gerbracht, J. H. 1937. Evergreens from seed. North and South Dakota Horticulture 10:46,48.

Jelley, M. E. 1937. Eastern red cedar. Journal of Forestry. 35:865–867.

Johnsen, T. N. 1959. Longevity of stored juniper seed. Ecology 40:487–488.

Little, E. L., Jr. 1971. Atlas of the United States. Vol I. Conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146, 9 p. w/base maps. Washington, D.C.

Meines, M. K. 1965. Juniper germination simplified. Tree Planters' Notes 70:6–7.

Pack, D. A. 1921a. After-ripening and germination of *Juniperus* seeds. Botanical Gazette 71:32–60.

Pack, D. A. 1921b. Chemistry of after-ripening, germination, and seedling development of juniper seeds. Botanical Gazette 72:139–150.

Parker, J. 1950. Germination of eastern redcedar seeds. Journal of Forestry 48:255–256.

Riffle, J. W., and H. W. Springfield. 1968. Hydrogen peroxide increases germination and reduces microflora on seed of woody species. Forest Science 14:96–101.

Stein, W. I. 1965. A field test of Douglas-fir, ponderosa pine, and sugar pine seeds treated with hydrogen peroxide. Tree Planters' Notes 71:25–29.

Trappe, J. M. 1961. Strong hydrogen peroxide for sterilizing coats of tree seed and stimulating germination. Journal of Forestry 59:828–829.

Van Haverbeke, David F. 1968. A population analysis of *Juniperus* in the Missouri River Basin. University of Nebraska Press, Lincoln, New Study Series No. 38, 82 p.

Van Haverbeke, D. F., and M. R. Barnhart. 1978. A laboratory technique for depulping *Juniperus cones*. Tree Planters' Notes 29(4):33–34.

Webster, C. B., and G. T. Ratliffe. 1942. A method of forcing quick germination of *Juniperus virginiana* seed. Journal of Forestry 40:268.

Wycoff, H. B. 1961. Redcedar seeding practices. Tree Planters' Notes 47:3–4.

Van Haverbeke, David F., and C. W. Comer. 1985. Effects of treatment and seed source on germination of eastern redcedar seed. USDA Forest Service Research Paper RM-263, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Germination of eastern redcedar (*Juniperus virginiana* L.) seeds was best with a 96-hour soak in citric acid (10,000 ppm), with 6 weeks of moist-warm (24°C) stratification, and 10 weeks of moist-cold (5°C) stratification. Geographic seed sources responded differently to treatment. Use of fresh seeds could reduce the time in moist-warm stratification, would improve germination, and would reduce interaction between seed source and treatment.

Keywords: *Juniperus virginiana*, germination, seed source

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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